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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

THE DEVELOPMENT OF A NEW LATERAL-CONTROL ARRANGEMENT

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SUMMARY

Development work on an arrangement using ailerons and spoilers for lateral control was carried out by the Vought-Sikorsky Aircraft Division of the United Aircraft Corporation on a small commercial airplane in flight and on an airfoil in a wind tunnel. Spoiler hinge moments were reduced by aerodynamic balance. The arrangement was then built into an experimental airplane and further improvements were adopted as the result of flight and tunnel tests.

The use of ailerons for lateral control with flaps up, spoilers with flaps full down, and gradual transition as the flaps are lowered was found to provide lateral control under the flight conditions for which they were best suited. The ailerons were of short span, permitting the use of long-span flaps, and were drooped to a relatively large angle when the flaps were deflected. A high maximum lift coefficient was thus attained. With large control deflections in the intermediate flap-angle range and spoiler effectiveness near neutral improved by "ventilating" the spoiler, the lateral control was satisfactory for the experimental airplane and was a definite improvement over that of a conventional control arrangement.

INTRODUCTION

The improvement of lateral control of airplanes at low speed has engaged the attention of engineers and research workers for some time. A rather difficult problem in lateral control was presented by the requirements of an observation airplane designed by the Chance Vought Aircraft Division of United Aircraft Corporation. The over-all dimensions were strictly limited; a low stalling speed was required; and excellent lateral control was desired. In order to use a monoplane arrangement with reasonable aspect ratio, a maximum lift coefficient of about 2.3, power off, had to be realized to obtain the required stalling speed of about 50 miles per hour. In order to obtain this high lift, the flaps would need to be of long span, which would necessitate short-span ailerons. The tests described in reference 1 indicated that a monoplane arrangement with a deflector-plate flap was feasible. A monoplane arrangement had an obvious advantage in performance over the alternative solution, a more lightly loaded biplane arrangement.

The problem in question was to obtain satisfactory lateral control in flight up to the stall, that is, up to the maximum lift of the airplane in flight. The object of the development was to insure that adequate control moments were available up to the stall. It was appreciated that an additional necessary condition for satisfactory lateral control is that damping in roll exist. A straight leading edge, low aspect ratio, and low taper ratio of the wing were considered to be sufficient items to include to avoid premature loss in damping in roll through an early stalling of the tip sections.

At the time the work was started, very little information was available on the aerodynamic requirements of lateral-control devices. Aileron and lateral-control design were on rather an empirical basis. The work of Weick and Jones (reference 2) published about this time made clear, however, how the motion of an airplane could be calculated if its derivatives were known.

Flight experience on a conventional biplane equipped with high-lift flaps giving a fairly high maximum lift coefficient showed the importance of providing a high rolling moment and keeping the adverse yawing moment low. It was apparent that an arrangement would have to be provided on the projected airplane to produce a much larger rolling-moment coefficient at high angles of attack than would be available with conventional ailerons and that the ratio of the adverse yawing moment to the rolling moment should be kept at a very low value.

Wind-tunnel tests provided data for a preliminary arrangement of controls. The arrangement was tested and gradually improved on a test airplane. Finally, an experimental airplane incorporating the lateral-control device was constructed and test flown.

The tests were carried out by the Chance Vought Aircraft Division (later the Vought-Sikorsky Aircraft Division) of United Aircraft Corporation during 1937-39.

Acknowledgments are made to Professors John R. Markham, Shatswell Ober, and Otto C. Koppen of Massachusetts Institute of Technology for helpful suggestions during early wind-tunnel tests and to Michael Gluhareff and Roger W. Griswold, II, who did the early work on various spoilers in conjunction with deflector-plate flaps in the Sikorsky wind tunnel. Mr. Griswold also assisted during the tests of the test F-24 airplane and W. F. Milliken, Jr., acted as observer on the test airplane investigation and carried out many of the detailed calculations in the analysis of the data and the application of the results to the experimental airplane. Acknowledgment is made to the work of the NACA published in references 2 to 7, which formed a starting point for the development and gave a rational method of correlating wind-tunnel and flight-test results and applying them to the design of the experimental airplane. The entire development was a project of the Vought-Sikorsky Aircraft Division of United Aircraft Corporation under Mr. R. B. Beisel, Chief Engineer.

WIND-TUNNEL TESTS

Two general series of arrangements were tested in the M.I.T. wind tunnel: Combinations of conventional ailerons of 0.20c with various rearwardly located upper and lower surface plain spoilers were tested, including the effect of drooping the ailerons on their effectiveness; tests were made of special spoiler arrangements developed at Sikorsky Aircraft in conjunction with the deflector-plate flap described in reference 1. The results of the tests were studied in connection with the tests reported by the NACA in references 3 to 6. It was concluded that sufficiently large rolling moments with low adverse yawing moments could be obtained and that flight tests would be necessary for further development of the projected arrangement.

FLIGHT TESTS

The preliminary design of a lateral-control arrangement to be adapted to a small commercial airplane was arrived at from the test results and the method of analysis outlined in reference 2.

As stated in the Introduction, the lateral-control arrangement was first tested on a Fairchild airplane, the F-24G, which will be termed the "test" airplane. The final design and the subsequent modifications were incorporated in an "experimental" airplane, the XOS2U-1. An attempt was made to have the arrangement on the test airplane as close as possible to that foreseen for the experimental airplane. The following factors were kept in mind, in addition to those related to the production of control moments:

1. The drag increment added to the wing with flaps up

2. The rigidity and simplicity of construction

3. The adaptability for modification during test

The Test Airplane

Original arrangement.- Tests totaling about 7 flight hours were made to develop a testing technique and to obtain characteristics of the unmodified airplane (that is, as received from the manufacturer) for use as a basis in evaluating results. The aileron-control characteristics of interest were rolling effectiveness, stick force, and adverse yaw. The test methods used were rather crude but more accurate data could have been obtained only by the use of expensive and complicated instruments.

The rolling power was determined by measuring the time required for the airplane to bank to a certain angle at various stick deflections at a given air speed (see fig. 8), keeping the rudder fixed at neutral.

A simple spring indicator installed on the top of the stick showed the amount of stick force. The stick-force indicator is shown in figure 9. The pilot trimmed the airplane at the selected speed, applied the stick against a previously set stop and, while the airplane was rolling, noted the force required to just hold the stick against the stop. The results are plotted in figure 10. The stick-position indicator shown in figure 9 could have been used instead of the stops with some sacrifice in accuracy.

The magnitude of the adverse yawing moment was roughly evaluated by noting the amount that the bank-indicator ball departed from center and the amount that the nose of the airplane moved in an opposite sense to the roll. Another method, but one that was discontinued because of the time involved, was to determine by trial and error the amount of rudder necessary to counteract the adverse yawing moment. (See fig. 11.)

The critical conditions for lateral control, especially for rolling effectiveness and adverse yaw, occur at low speeds. The stick forces, of course, are critical at high speeds. The time-to-bank and the adverse-yaw tests were therefore run at an air speed slightly above the stalling speed. This speed was high enough that stalling or flow-separation effects did not enter into the results but low enough that it could be regarded as a low gliding speed. Enough runs were made at a higher speed to indicate the trend of the variables with speed.

Modified arrangement.- The arrangement selected for the initial set-up consisted of flaps and ailerons both of the deflector-plate type and both arranged to be deflected (drooped) 50° by separate cranks. A spoiler was installed just forward of the ailerons. An additional short-span spoiler, which could be joined to the main spoiler, was provided ahead of the outboard end of the flaps. (See fig. 1(a).)

A method was devised by Mr. R. B. Beisel for operating the spoiler, up only, one side at a time. By means of a Watt's linkage (figs. 2 and 3) a movement of the stick to the right from neutral would deflect the right spoiler upward while the left spoiler remained stationary, and oppositely for the left movement. The control for the deflector-plate ailerons was set up with a conventional differential; the drooping was so accomplished by a worm-and-sector arrangement that the relation between stick and aileron angles measured from the stick-neutral position was unchanged by drooping the ailerons.

The appearance of the airplane as used in the flight tests after initial modification is shown in figures 4, 5, and 6. Dimensional data are as follows:

Wing area, square feet	193.6
Wing-span, feet	36.33
Wing chord, feet	5.50
Wing aspect ratio	6.83
Flap area (total, back of hinge), square feet	16.42
Flap span (total), feet	14.06
Flap chord, feet	1.17
Maximum flap deflection, degrees	50
Aileron area (total), square feet	17.70
Aileron span (total), feet	15.18
Aileron chord, feet	1.17
Maximum aileron droop, degrees	50
Spoiler area (total), square feet	12.43
Spoiler span (total), feet	20.66
Spoiler chord, feet	.60
Spoiler hinge location, percent wing chord .	68.1

In figure 7 are shown the spoiler stick, which was also hinged fore and aft and could be secured in the spoiler-neutral position; the flap and the aileron droop operating cranks; and the detachable link provided for tests with combined spoilers and ailerons,

After the preliminary tests with the initial set-up, the test airplane was successively modified by 27 changes to the spoilers and ailerons, tests being made to determine the improvement. Flight tests with the modified airplane, both of lateral-control and flap characteristics, occupied 11 weeks and involved 48 flights.

The same general methods were used in the tests of the modified airplane as were used in the tests of the original airplane except that only pilot's observations on adverse yaw were made and, in general, the number of points for stick-force and rolling-effectiveness measurements were kept at a minimum. No adjustable stops were provided for the spoiler control but the spoiler deflections were read from an indicator located just above the windshield.

The effects of flaps, spoilers, ailerons, and aileron droop were all qualitatively explored under different conditions. In the modified arrangement, deflector-plate flaps were used as both flaps and ailerons. The tendency of the spoilers to ride up to a high floating angle above the neutral setting was eliminated by the installation of a shield below the spoiler, as shown in figure 1(b). In an attempt to reduce the spoiler hinge moment, aerodynamic balance was tried as shown in figure 1(c).

In general, the spoilers were effective in producing roll with little or no adverse yaw. The stick forces were relatively high. The effectiveness of the spoilers was greater with flaps and ailerons down than with them up, and their effectiveness seemed to increase at low speeds. With flaps down, the spoilers were overbalanced near neutral, but the tendency toward overbalance was eliminated by the shield shown in figure 1(b). The test data were used to evaluate, by the method of reference 2, the spoiler rolling-moment coefficient obtained with flaps and ailerons down. Somewhat higher values were obtained than would be indicated from the data of references 4 and 5, obtained without a slotted flap behind the spoiler. The belief that the flap slot immediately behind the spoiler increased its effectiveness was confirmed by wind-tunnel tests.

A great deal of the modification and testing was concerned with the reduction of stick forces. The basic balance arrangement shown in figure 1(c) is similar to the nose balance used on ailerons. Various modifications were tried to smooth out the curve but the desired linear curve of stick force with deflection was not reached. A re-rigging of the control system to limit the spoiler deflection from 70° to 40° reduced the stick force. Experience indicated that some departure from the linear variation in stick force and effectiveness could be tolerated if a more powerful lateral control were gained.

The rolling effectiveness near neutral was low and a "dead spot" existed for about 2° of stick travel. The ineffective range was reduced to 1° by decreasing the maximum spoiler deflection to 40°. The range was reduced with the aileron slot closed but closing was considered unadvisable because it was necessary to have the flap and the aileron slots open for their favorable effect on maximum lift and spoiler effectiveness at moderate and large deflections. The poor effectiveness was not a case of lag or sluggishness; when the spoiler was deflected outside the short ineffective range, the airplane began immediately to roll. Typical results obtained with the spoilers are shown in figures 12 and 13. On account of the relatively good performance of the spoilers with flaps and ailerons down and their relatively poor performance at higher speeds with flaps and ailerons neutral, it was decided that in the experimental airplane the use of the spoilers would be restricted to the flaps-down condition and the ailerons would be used for control with the flaps up.

The deflector-plate ailerons were found to be adequate as a control when they were not drooped but their stick forces were very heavy. When the ailerons were drooped, the stick forces became progressively lighter and were overbalanced when the ailerons were drooped beyond an angle of about 22°. At droop angles greater than 20° with the flaps down and at low speeds, their effect in producing adverse yawing moment was just about as great as their effect in producing roll, and they were entirely unsatisfactory as a control. The flaps caused a marked reduction in the stalling speed of the airplane; a maximum lift coefficient of about 2.4, power-off, was obtained with flaps down 50° and an aileron droop angle of 35°. In an attempt to reduce the aileron stick forces, the ailerons were modified by changing the section; the deflector-plate was removed and the nose shape was changed. Although more nose balance was provided than on the original F-24 airplane, the stick force was high. This high stick force was taken to indicate that the hinge axis should be located within the airfoil contour.

A few tests were made with a combination of the spoilers and the ailerons, a link being used to join the two control sticks. The characteristics of the combination appeared to be approximately the total of the separate controls in respect to rolling effectiveness, stick forces, and adverse yaw. It was found that deflection of the spoiler tended to make the aileron behind it ride up, contributing to a reduction of stick force for the combination.

The main conclusions arrived at from the tests of the F-24 (test) airplane are:

1. Spoilers of the approximate type and proportions tested gave satisfactory and much greater rolling effectiveness than drooped ailerons at high lift coefficients with the flaps down.

2. With the hinge line of the spoilers at the chord location tested, the lag was negligible.

3. The under surface of the spoilers should be separated or shielded from the air flow through the flap or aileron slot to prevent overbalance near neutral.

4. The effectiveness of the spoilers was greatest with the flaps and ailerons down and was much less with the flaps and the ailerons up.

5. The effectiveness of the spoilers was appreciably greater with the slot open than with the slot closed. The shield did not critically affect this characteristic, and moving the trailing edge of the spoiler ahead of the trailing edge of the shield also had no critical effect.

6. The effectiveness of the spoilers near neutral tended to be low and therefore the control linkage should be designed to move them up from their neutral position as rapidly as possible consistent with avoiding undesirable inertia effects.

7. A satisfactory control can be obtained by a combination of spoilers and ailerons.

8. The adverse yawing moments from the spoilers with the flaps down were low and were much lower than those from drooped ailerons.

9. Although it may be difficult to obtain a linear variation of stick force and rolling effectiveness with stick deflection, some departure from linearity can be tolerated in view of the other desirable features of the control.

The Experimental Airplane

A study of the results of the test airplane led to the final decision that on the experimental airplane spoilers would be used for lateral control with flaps down for landing and ordinary ailerons would be used for control with flaps up for cruising. An arrangement that gave a continuous and gradual shift from aileron control to spoiler control as the flaps were deflected was found to be possible.

A diagram of the spoiler and aileron arrangement installed on the experimental airplane is shown in figure 14. The aileron design was a compromise based on a normal hinge location and was intended to have reasonably low hinge moments and a reasonable slot when drooped. The aileron chord back of the hinge was 20 percent and the nose-balance length and shape were such that a contracting slot was provided for all aileron deflections to about 35° down.

The spoiler shape was simplified and the spoiler was moved sufficiently far forward to provide for a complete separation from the aileron or flap slot and for a downward movement of 3° into the wing. The 3° movement made it possible to start the spoiler moving in the upward direction before the neutral position was reached and gave appreciably higher spoiler deflections for small stick movements near neutral than could otherwise have been obtained. (See fig. 15.) The linkage installation is shown in figure 16; the position is for the spoiler neutral.

As a result of tests in the Sikorsky wind tunnel, a simple vane was decided upon as a balance. Provision was made in the lower surface of the wing to receive a vane mounted on arms attached to the spoiler; the size of the vane could be changed during the modifications.

The size and the deflections of the control surfaces were computed as suggested in references 2 and 7, using as a basis the results of the Sikorsky wind-tunnel tests, the flight tests on the test airplane, and the NACA tests reported in references 4, 5, and 6. The data in reference 7 for the "average airplane" were used to determine the required rolling-moment coefficients, correcting L_p for taper and aspect ratio. A criterion of required wing-tip displacement of 4.2 feet in 1.0 second was adopted. The ailerons were of 32 percent semispan and were designed to give a rolling-moment coefficient that would satisfy the criterion for low speeds with the flaps up. The spoiler span was 41 percent of the semispan, as shown by the following dimensional data:

Wing area, square feet	261.9
Wing span, feet	36.0
Wing aspect ratio	4.9
Wing taper ratio (tip chord to root chord) .	.69
Wing mean aerodynamic chord, feet	7.45
Flap area (total, back of hinge), square feet	35.1
Flap span (total), feet	19.7
Flap chord, percent wing chord	21.2
Maximum flap deflection, degrees	40
Aileron area (total, back of hinge), square feet	13.4
Aileron span (total), feet	11.5
Aileron chord (constant, back of hinge), feet	1.35
Maximum aileron droop, degrees	30
Spoiler area (total), square feet	9.98

Spoiler span (total), feet	14.7
Spoiler chord (average), percent wing chord	10.3
Spoiler hinge location (average), percent wing chord	68.0
Spoiler motion . . . . degrees up	50
degrees down	3

The lateral-control operating system of the experimental airplane is shown schematically in figure 17. The aileron drooping mechanism, the change-over mechanism for the shift in control, and the flap mechanism were all operated from the same crank.

The change-over unit mounted in the airplane is shown in figure 18. The unit is rocked laterally by the pilot's control stick about a fore-and-aft axis through its center. The aileron droop is obtained with the unit shown in figure 17. The arrangement was suggested by Mr. F. C. Albright.

In figure 19 are shown the maximum deflection of the ailerons and spoilers plotted against flap deflection. The total of the aileron and spoiler deflection is substantially constant between the two end values. If the total aileron deflection with flaps up is taken as representative of a satisfactory control for this condition and the maximum spoiler deflection is taken as a satisfactory control for the flaps-down condition, then to a first approximation the control power at intermediate flap settings is represented by the combined total aileron and spoiler deflections, and satisfactory control is to be expected.

The experimental airplane as set up for the initial tests is shown in figures 20, 21, and 22. It had no spoiler balance and had a separate control for the change-over unit. After the preliminary flights, the spoiler balance (fig. 23) was installed and the change-over unit was connected as shown in figure 17.

With flaps up the aileron control was very light but, in the pilot's opinion, it was just on the edge of being adequate in power at low speed. With the flaps down and the ailerons drooped 30°, the spoiler control was as powerful as expected and the airplane had exceptionally low adverse yaw. The airplane could be rolled from a banked turn on one side to one on the other at low speed and high lift coefficient with the rudder free and with almost no yawing or sideslipping. For intermediate flap deflections the maximum rolling effectiveness was unsatisfactory, being less than with flaps up and appreciably less than with flaps full down.

The curves of figure 19 show how the total deflections were improved in the intermediate flap-setting range by a modification of the differential bell crank and an increase in maximum stick throw in this range. The stick forces at the intermediate flap settings were appreciably lower than at the extremes owing to the combined effects of aileron overbalance at high droop angles, increased mechanical advantage of the stick, and effect of the deflected spoiler on the up-going aileron.

With flaps full down and spoilers as the sole control, the aerodynamic balance was reasonably effective but the control had an unusual "feel." The pilot, however, soon became accustomed to the control and encountered no difficulty in maneuvering or landing. It was felt that the great improvement in control effectiveness (rapid rolling combined with very low adverse yaw) over that possible with ordinary ailerons more than offset the unusual feel of the control. The feel was definitely not due to lag, sluggishness, or inertia effect.

Flight tests were also made on the unmodified experimental airplane to determine the variation in stick force and time to bank with stick deflection. The results are plotted in figures 24 and 25.

Wind-tunnel tests were conducted on a rectangular wing model with an arrangement similar to the one on the experimental airplane. The spoiler characteristics were found to be affected by the slot between the flap or aileron and the wing. Typical curves showing the effect on lift with slot open and closed are shown in figure 26. Passages were drilled in the model to connect the balance recess with the spoiler recess and the model was again tested. The improvement with "ventilation" is shown in figure 26. The hinge-moment results with the ventilated spoiler indicated that a smoother variation of stick force would be obtained.

The spoiler on the experimental airplane was ventilated by omitting the inner covers over the recesses for the spoiler balance and under the spoiler, as shown in figure 27. The appreciable improvement in stick force and rolling effectiveness can be seen by comparing figures 28 and 29 with figures 24 and 25, which are for the same flight conditions. The curves of figures 25 and 29 are drawn to be symmetrical about certain points shown on the plots. The points have been transferred to the origin in figure 30 where the results are more fairly compared. When the modifications were made, the spoiler balance was also reduced in area, which accounts for the increase in force between figures 24 and 28.

This new lateral-control arrangement has been installed on the production versions of the same model as the experimental airplane (the XOS2U-1). Certain improvements in the mechanical arrangement simplified the system and an improved spoiler linkage made possible a more rapid rate of spoiler deflection from neutral. In a second experimental model, the operation of the flaps, the aileron droop, and the change-over unit was made hydraulic.

The main conclusions arrived at from tests of the experimental airplane are:

1. The lateral-control arrangement developed provided a higher maximum lift coefficient, a lower stalling speed, and a more effective lateral control than could have been obtained with ordinary ailerons drooped to a reasonable angle.

2. The drag increase introduced by the spoilers was negligible.

3. The attainment of a high maximum lift coefficient made possible the use of a monoplane with greater aerodynamic efficiency and performance than would have been possible with a biplane of larger wing area.

4. The development is a step in the direction of the use of full-span flaps. It utilizes ailerons and spoilers in the flight conditions for which their characteristics are basically suited.

5. The present lateral-control arrangement is particularly adapted to relatively small airplanes of low aspect ratio and low taper ratio. For other types of airplane in which control at low speeds and high lift coeffi-

cients is of great importance, it is believed that the use of the spoiler-type control should be considered, either alone or in combination with ailerons.

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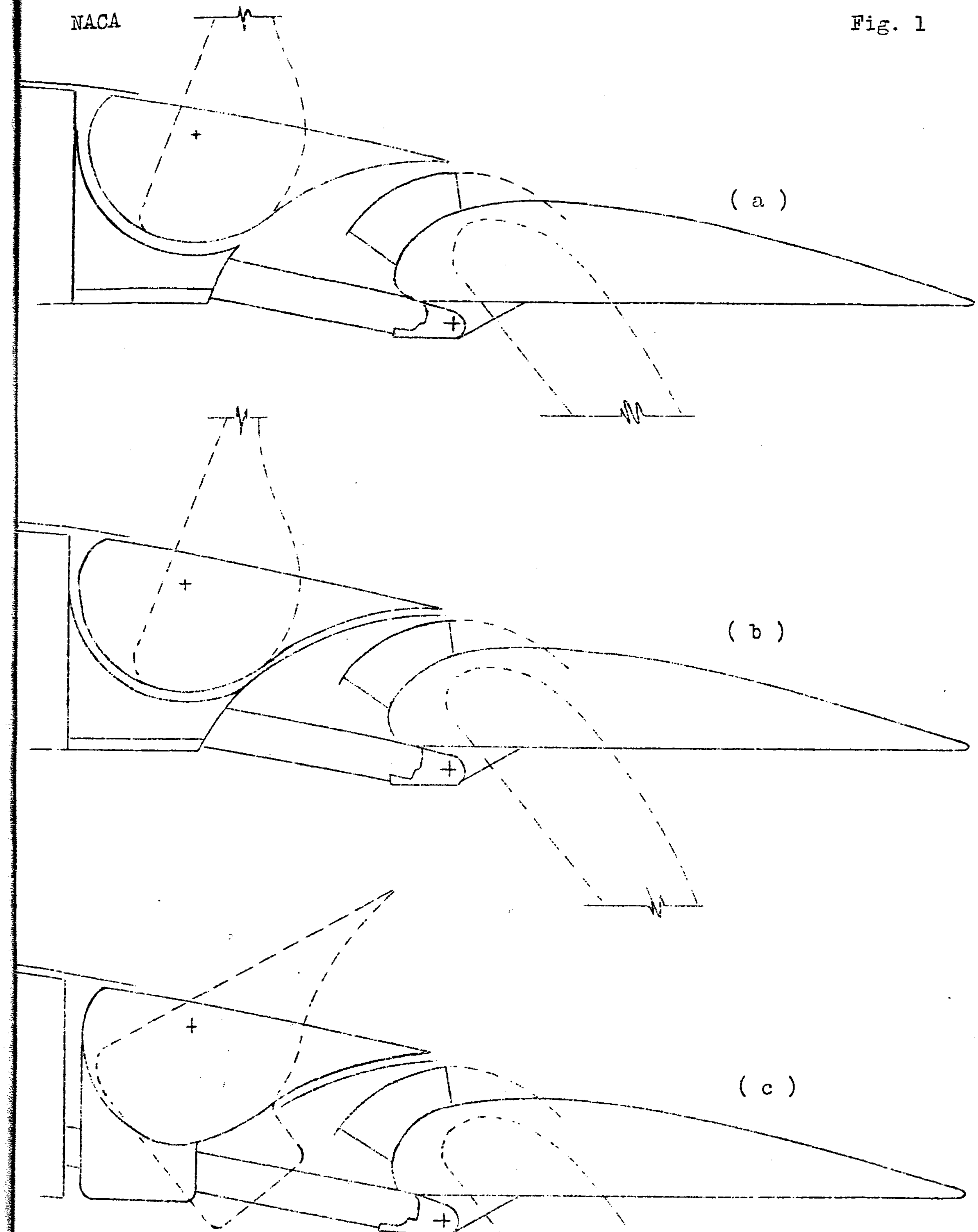

(a) Initial set-up of deflector plate flaps and ailerons.
(b) Shield to separate under side of spoiler from flap slot.
(c) Basic balance arrangement.

Figure 1.-Spoiler and aileron arrangements of the test airplane.

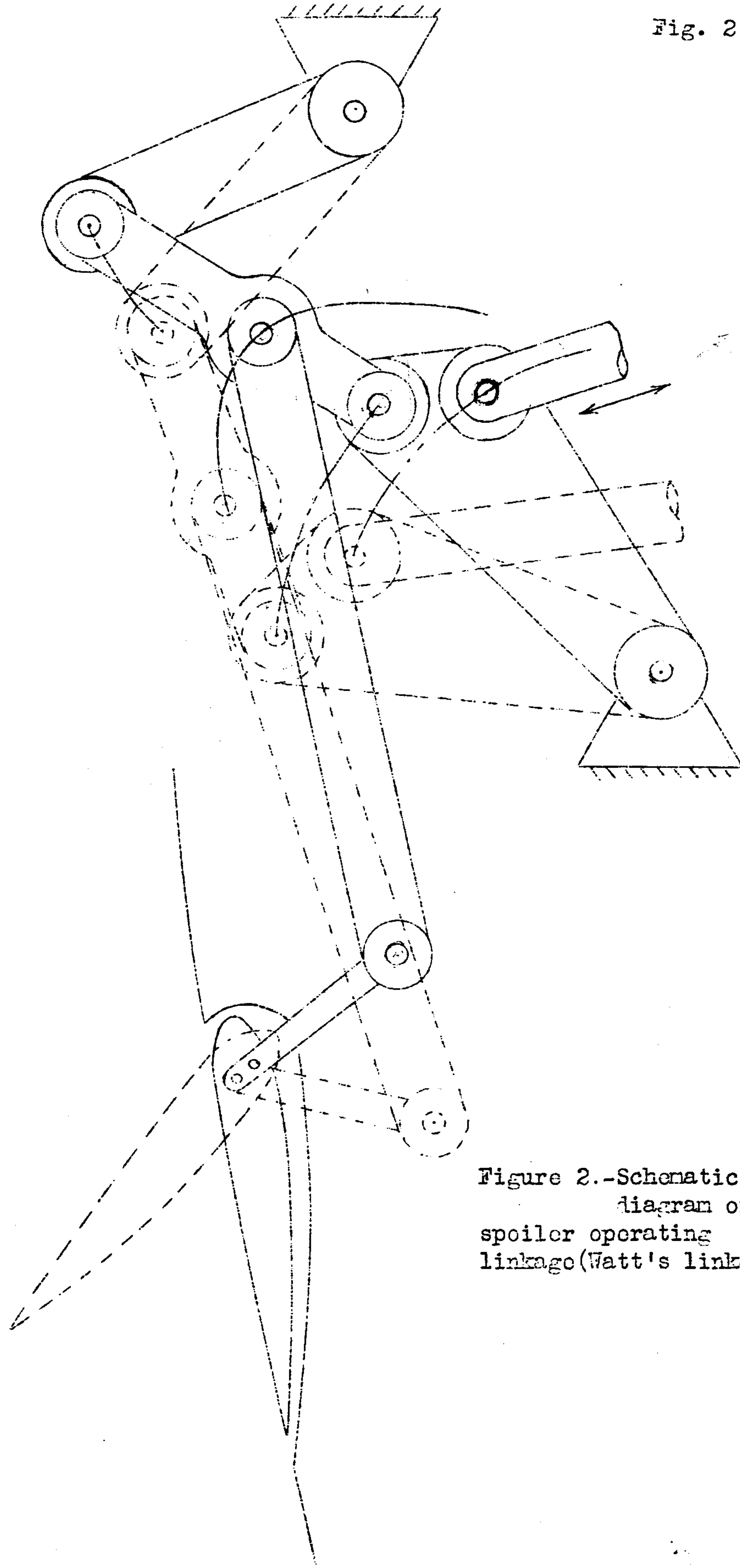

Figure 2.-Schematic diagram of spoiler operating linkage(Watt's linkage).

NACA Fig. 3

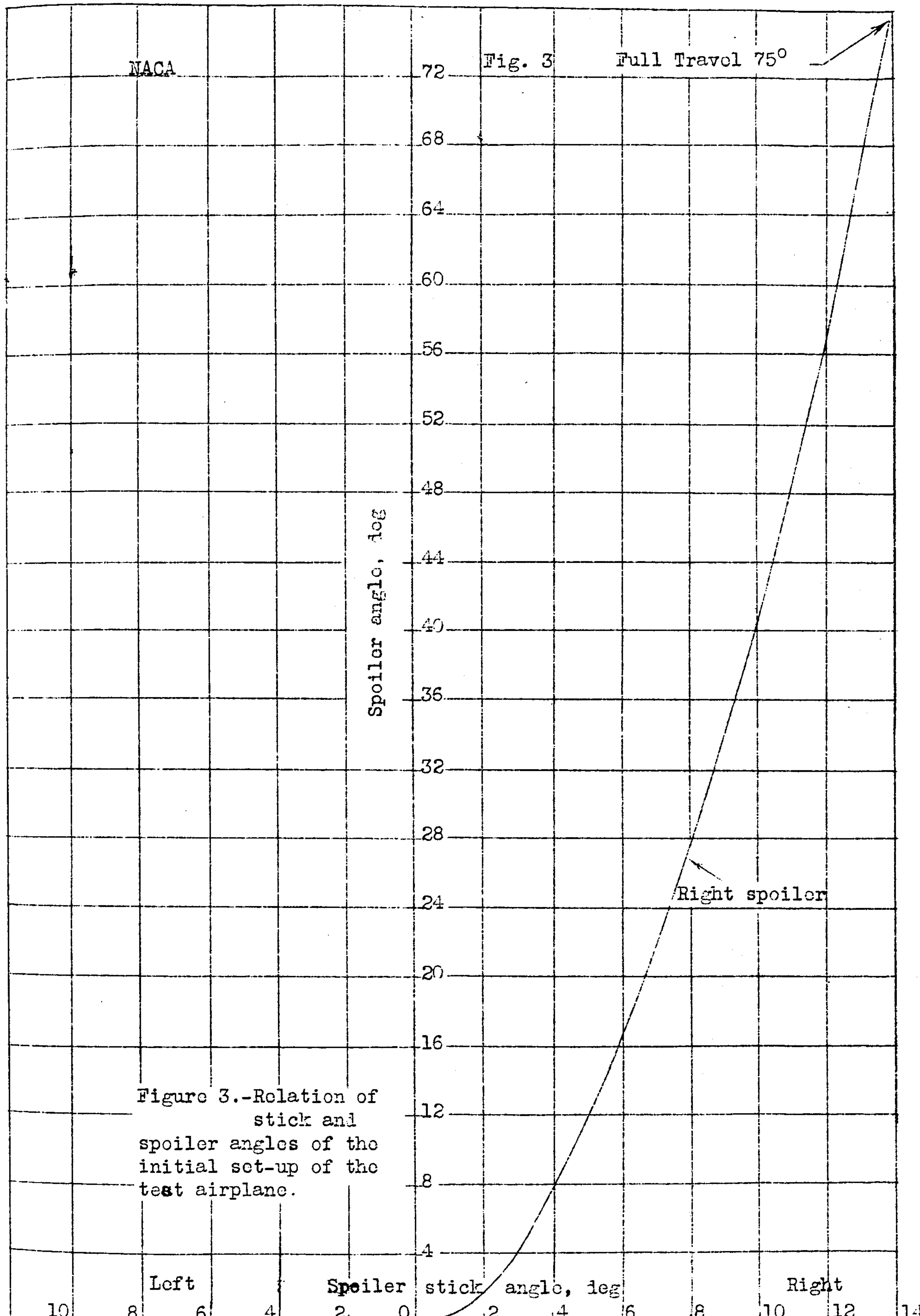

Figure 3.-Relation of stick and spoiler angles of the initial set-up of the test airplane.

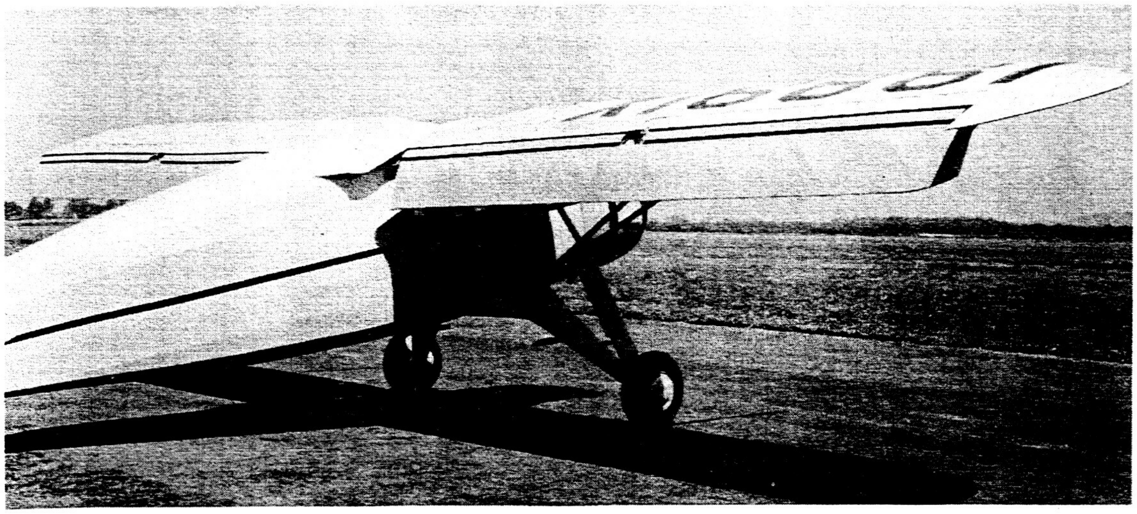

Figure 4.-Flaps and aileron drooped downward, spoilers neutral, modified test airplane.

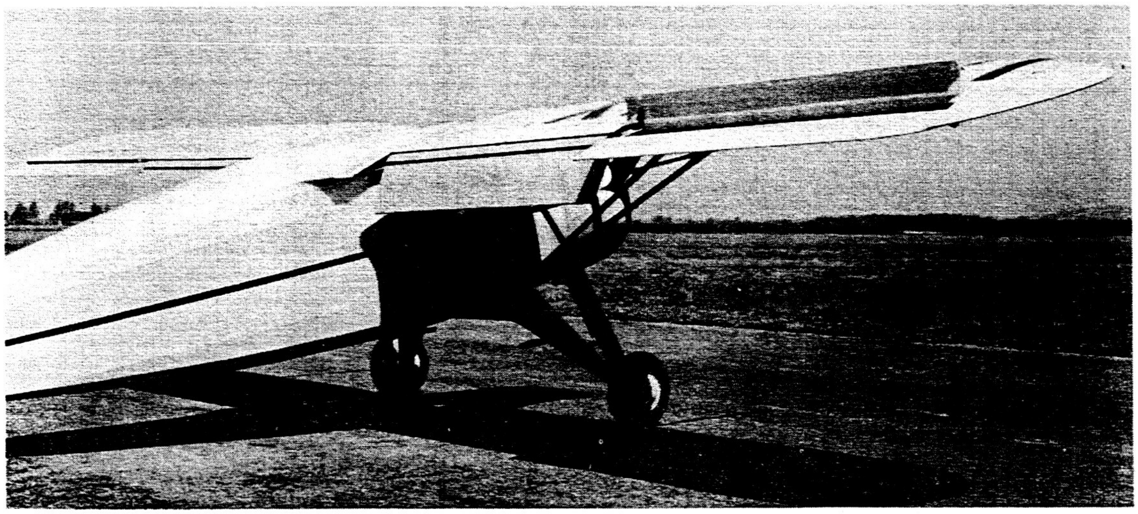

Figure 5.-Flaps down, ailerons undrooped, spoiler deflected, modified test airplane.

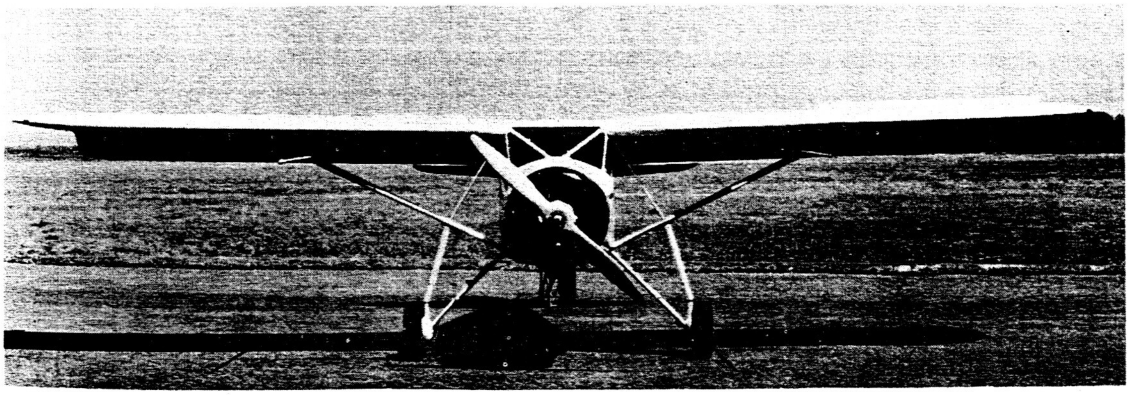

Figure 6.-Flaps and ailerons drooped, spoilers deflected, modified test airplane.

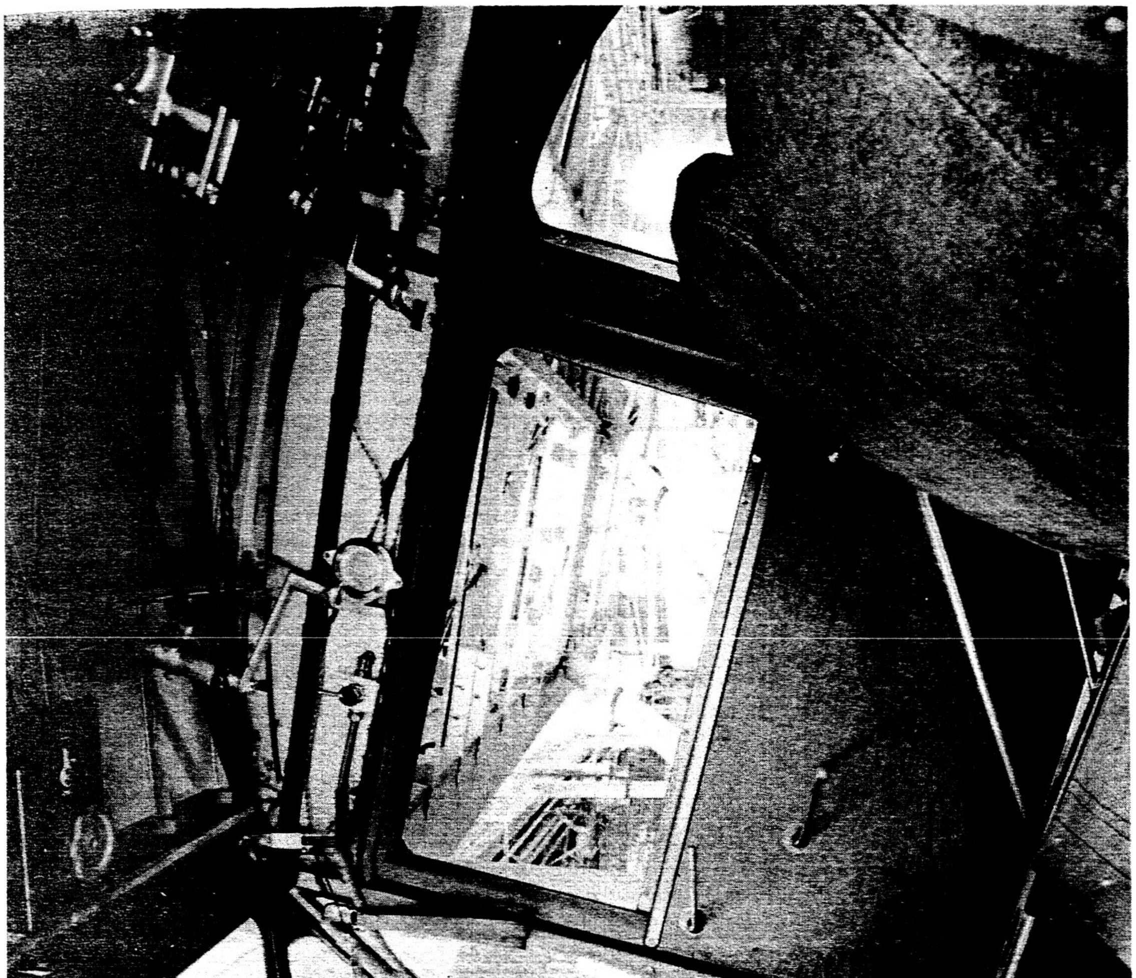

Figure 7.- Cabin and controls of the modified test airplane.

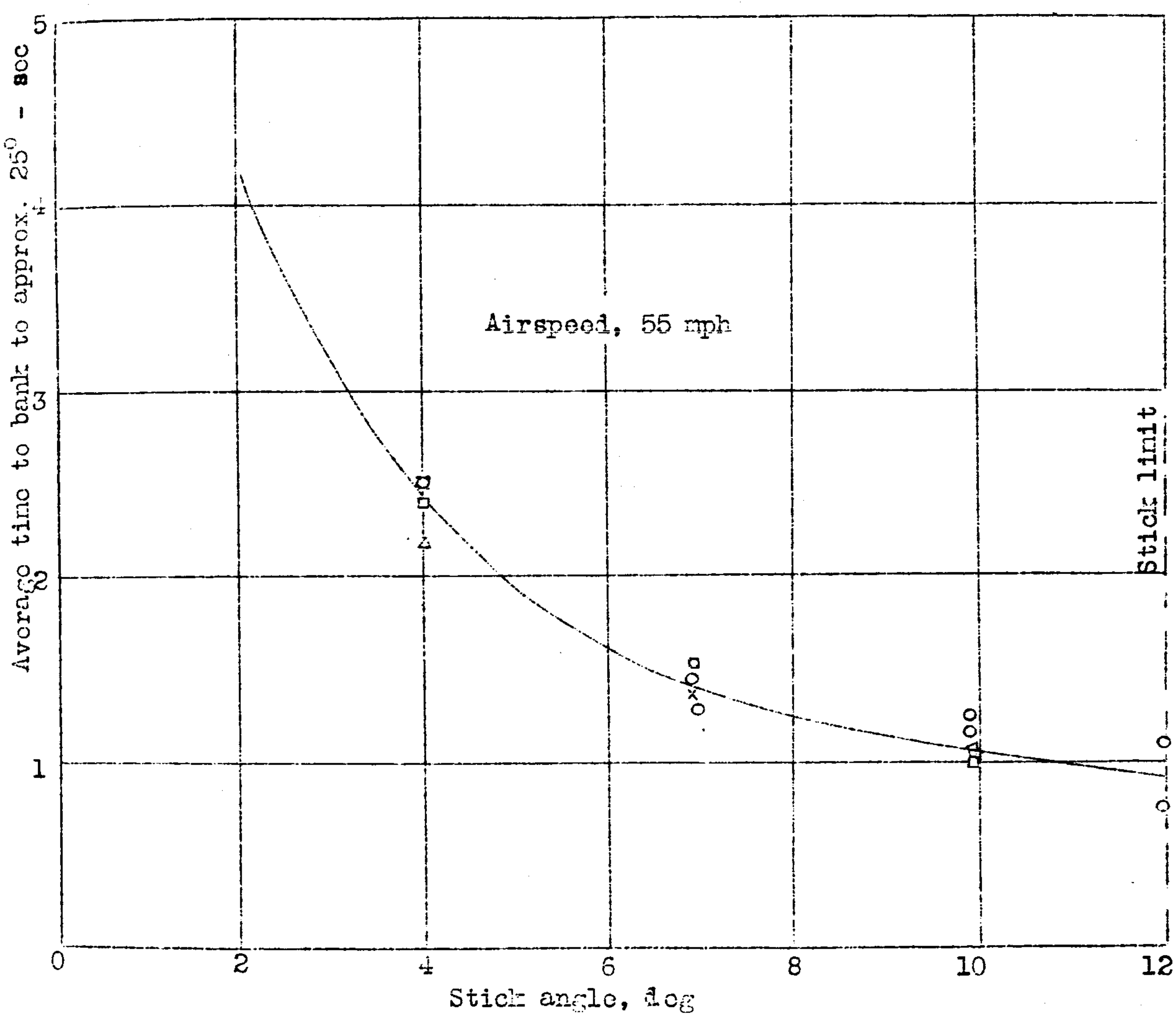

Figure 8.- Variation of time to bank with stick angle for the test airplane in the original condition.

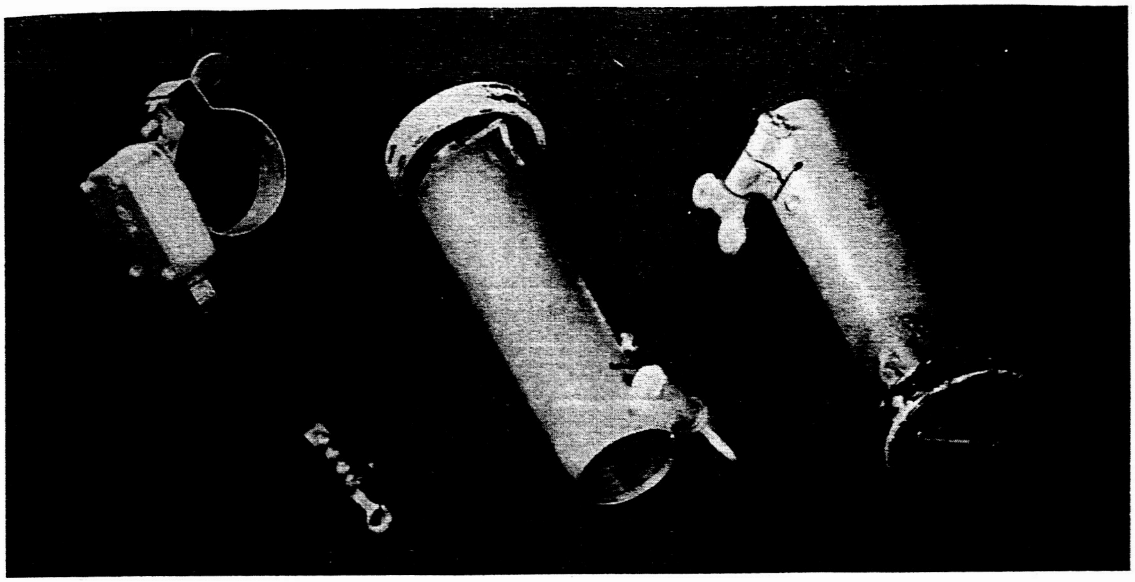

Figure 9.- Stick-force and stick-position indicators.

Figure 23.- Spoiler balance for the experimental airplane, neutral and deflected.

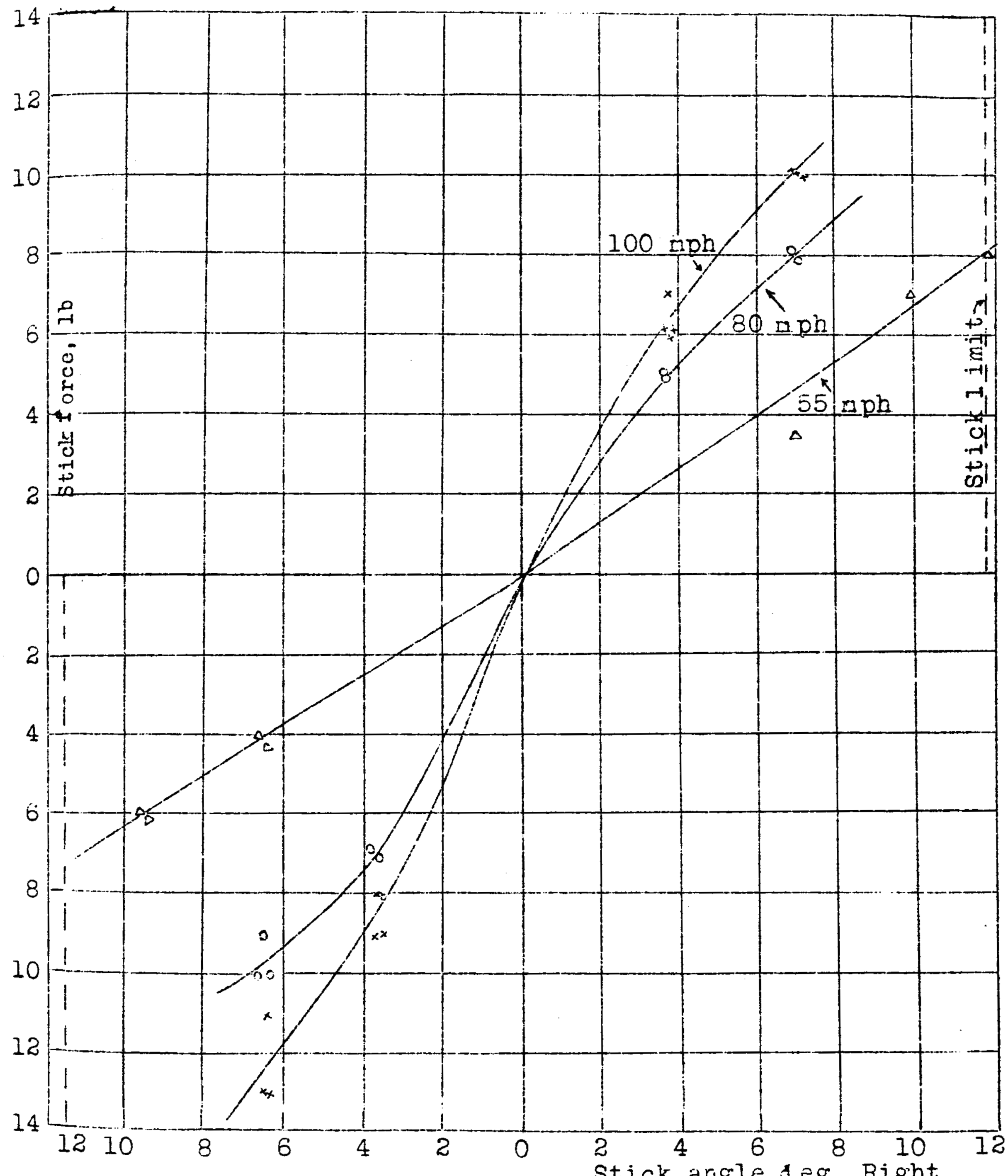

Figure 10 - Variation of stick force with stick angle for the test airplane in the original condition.

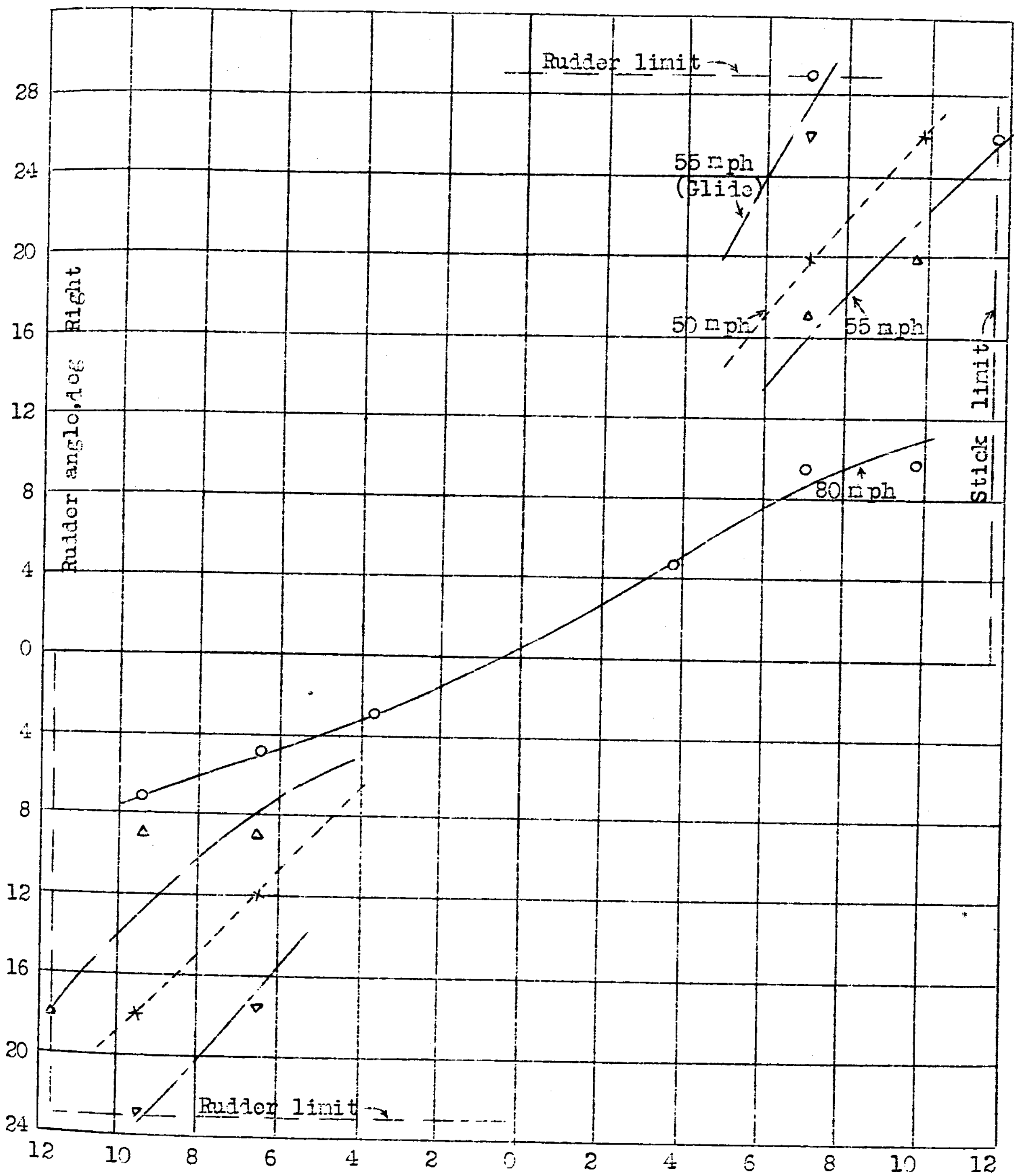

Figure 11.-Variation of rudder angle required for specified banking motion with stick angle for the test airplane in the original condition.

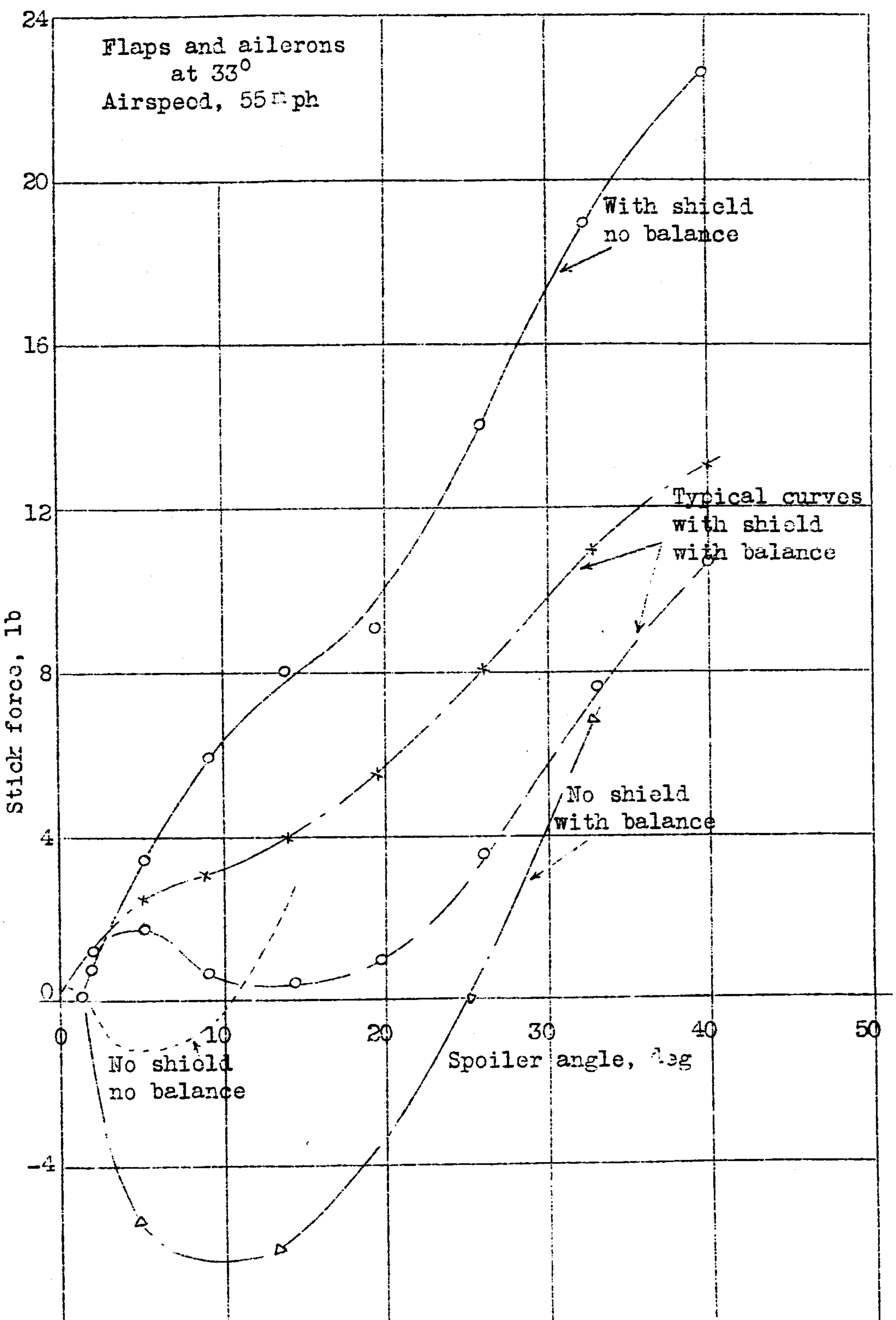

Figure 12.-Variation of stick force with spoiler angle for various arrangements of the test airplane in the modified condition.

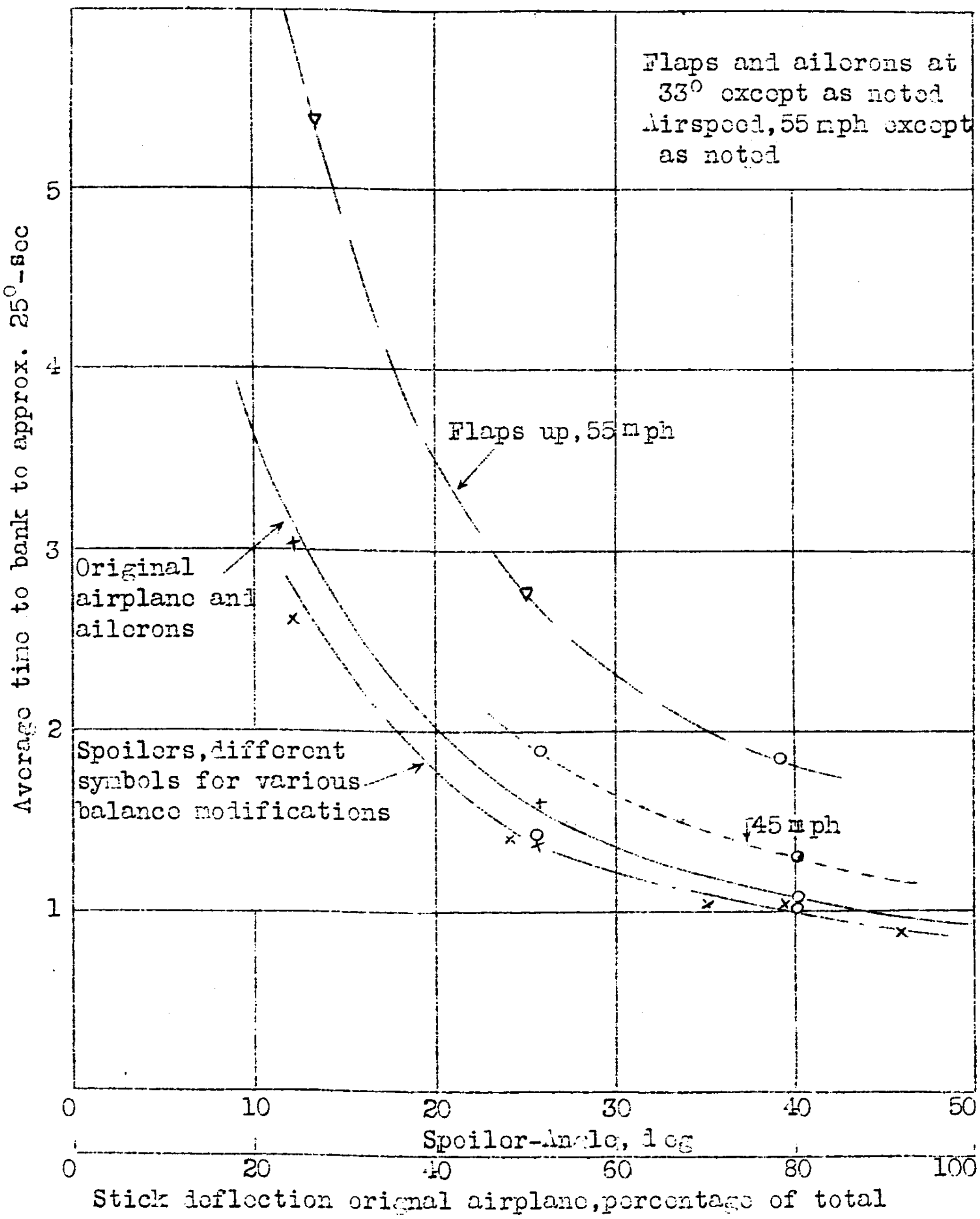

Figure 13.-Variation of time to bank with spoiler angle for the test airplane in the modified condition.

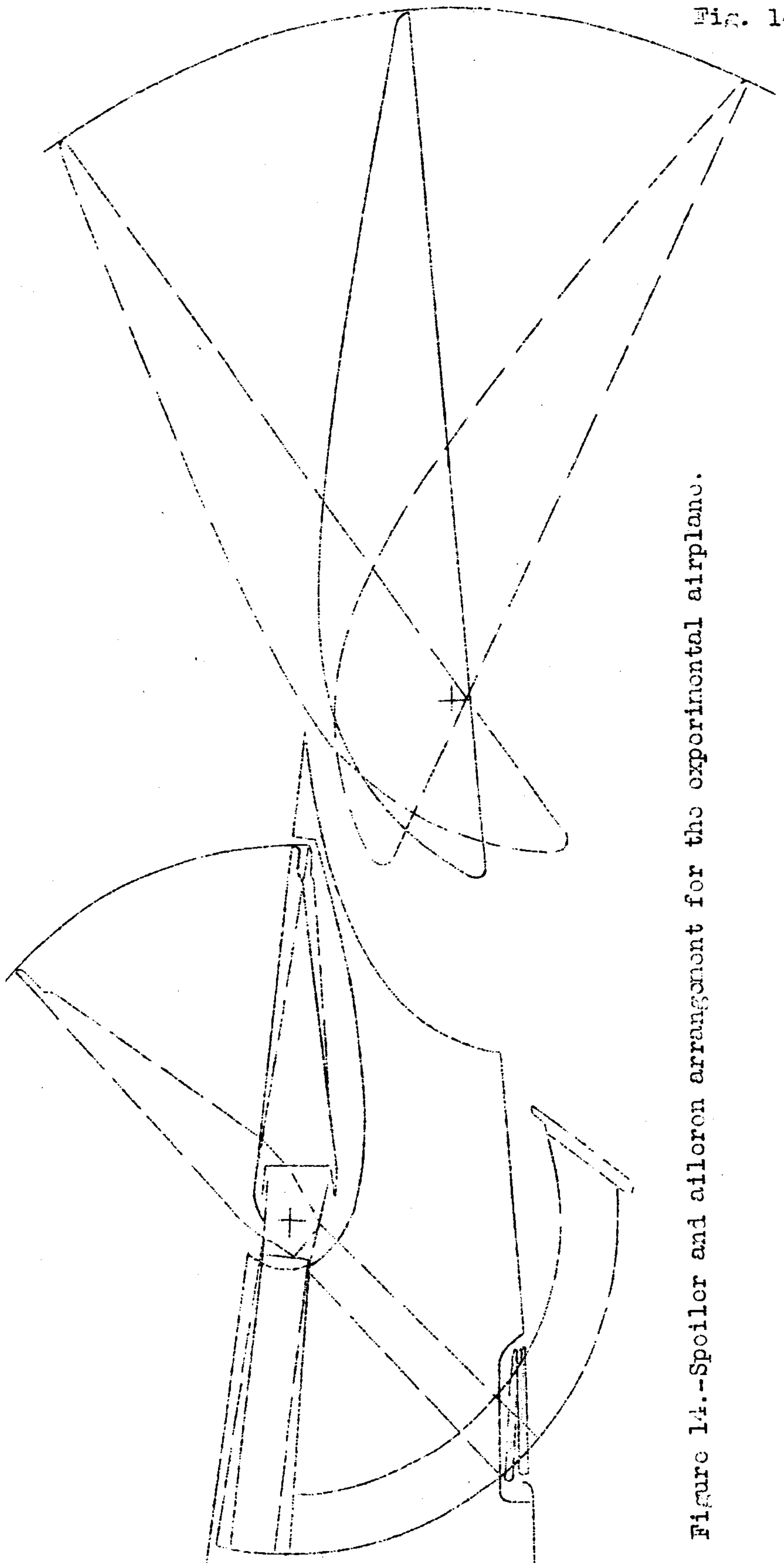

Figure 14.-Spoiler and aileron arrangement for the experimental airplane.

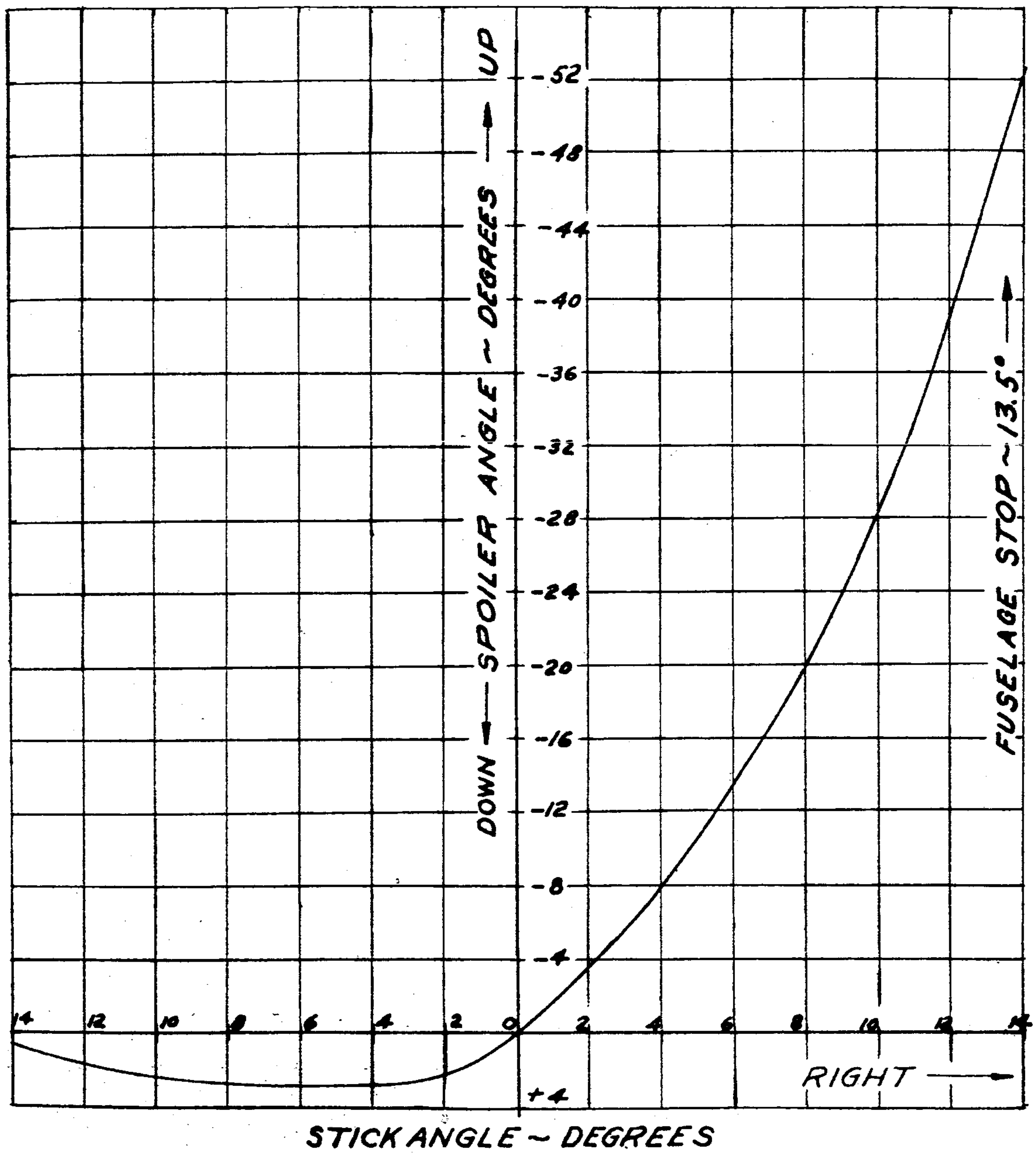

Figure 15.- Relation of stick and spoiler angles for the experimental airplane.

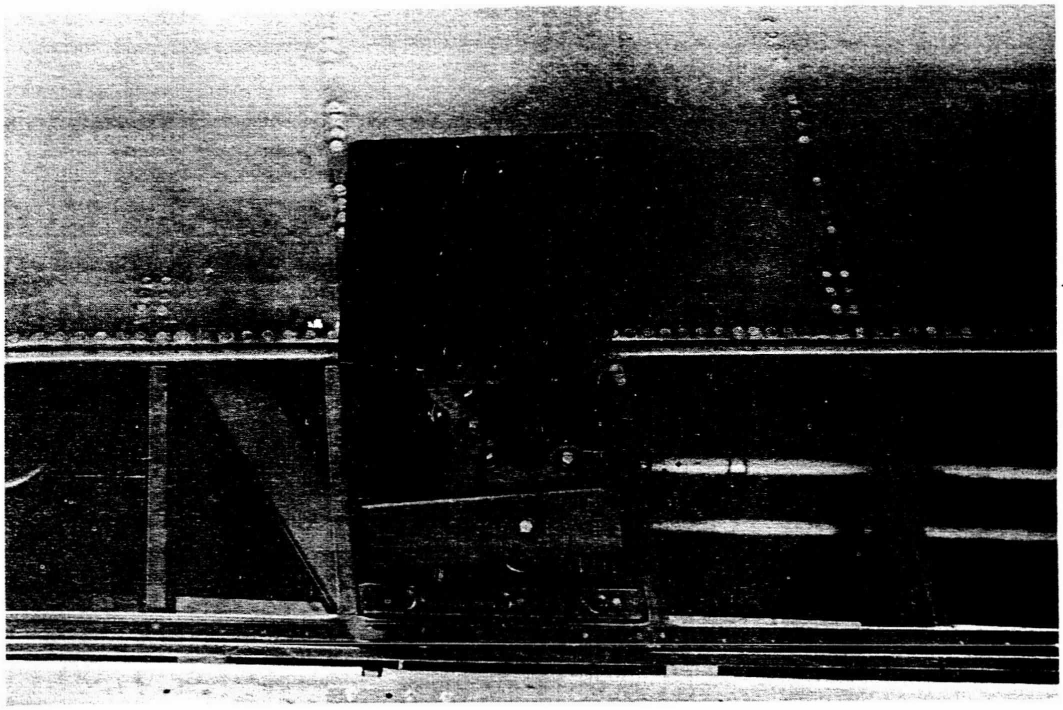

Figure 16.-Spoiler operating linkage (Watt's linkage) for the experimental airplane.

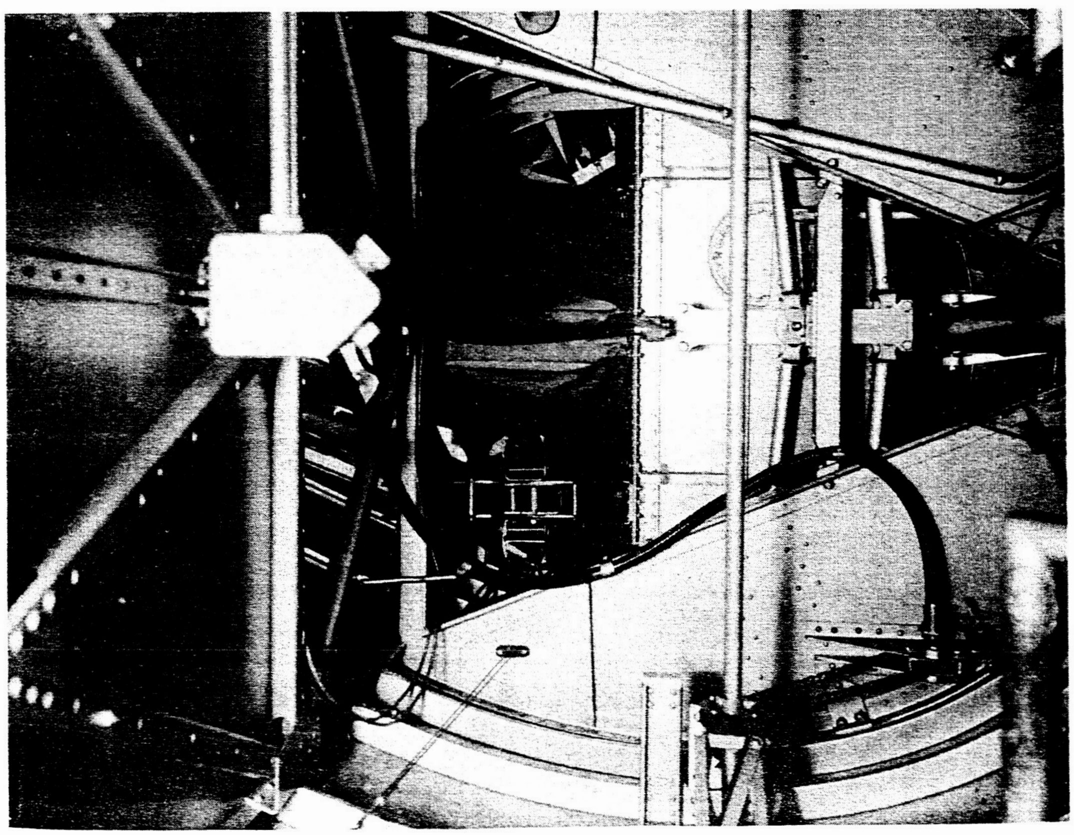

Figure 18.-Change-over unit of the experimental airplane.

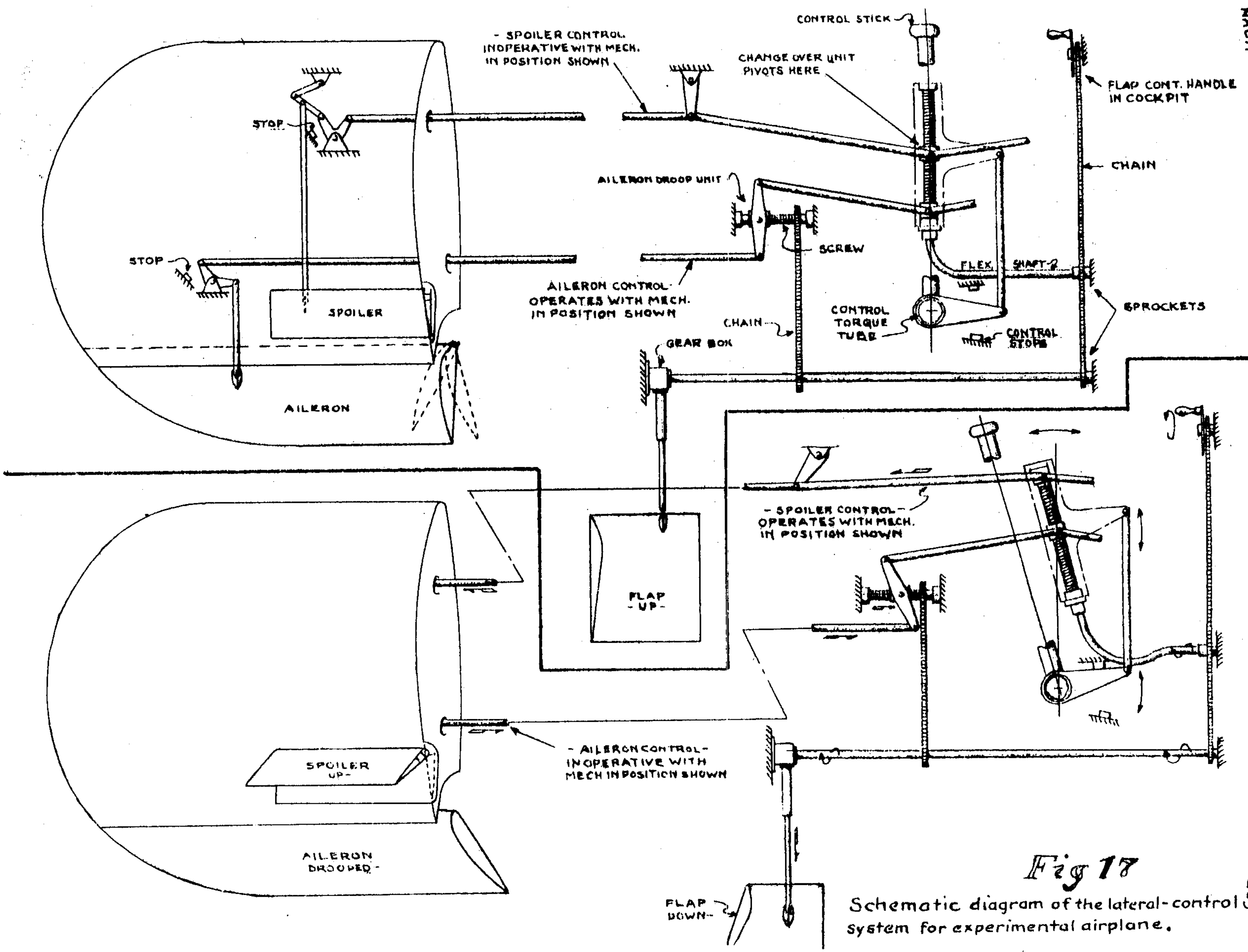

Fig 17

Schematic diagram of the lateral-control system for experimental airplane.

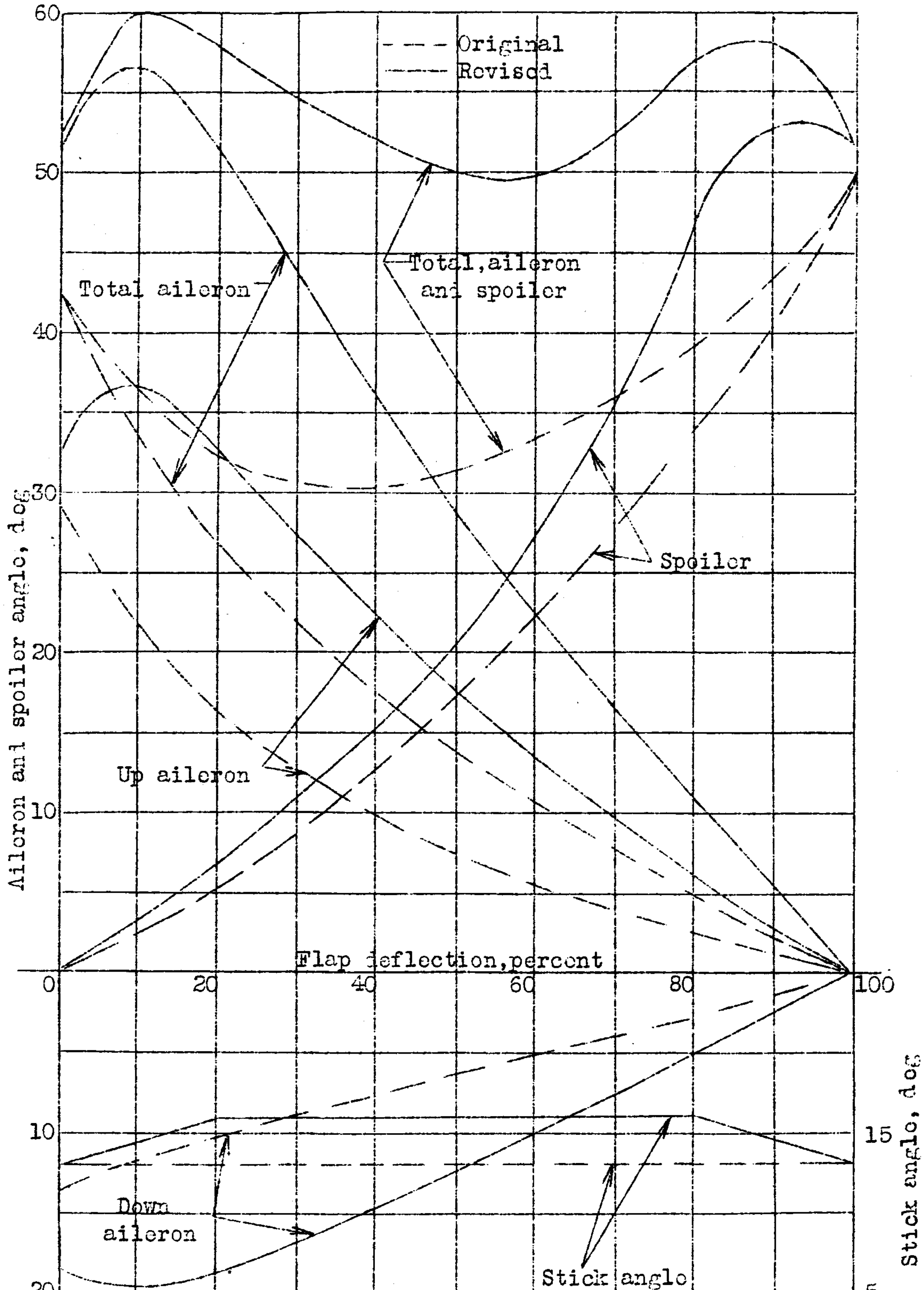

Figure 19.-Relation of maximum control deflections to flap setting for the experimental airplane.

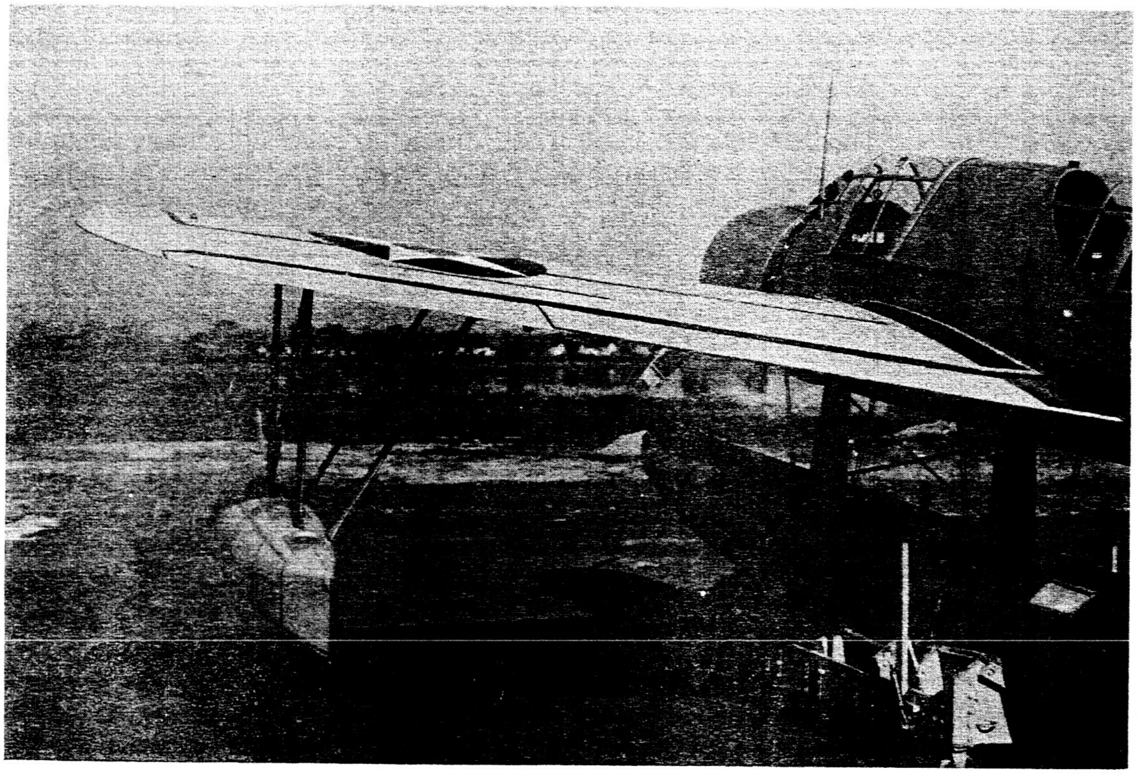

Figure 20.-Wing with flaps,ailerons,and spoilers neutral on the experimental airplane.

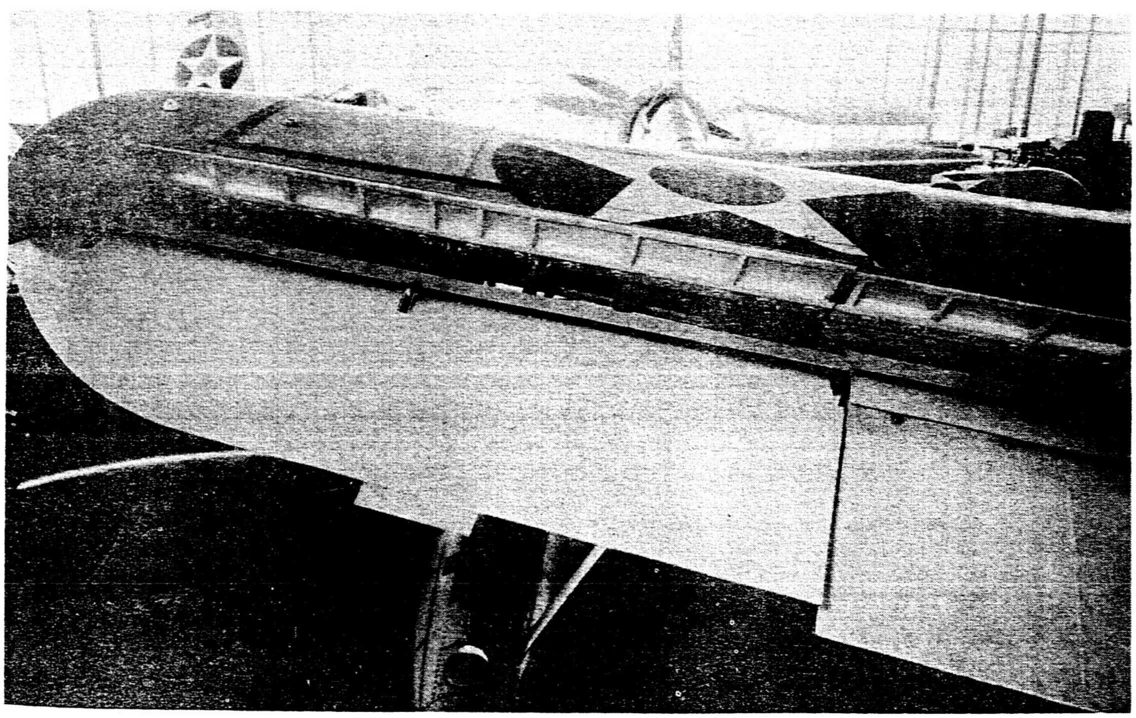

Figure 27.-Spoiler ventilation on the experimental airplane.

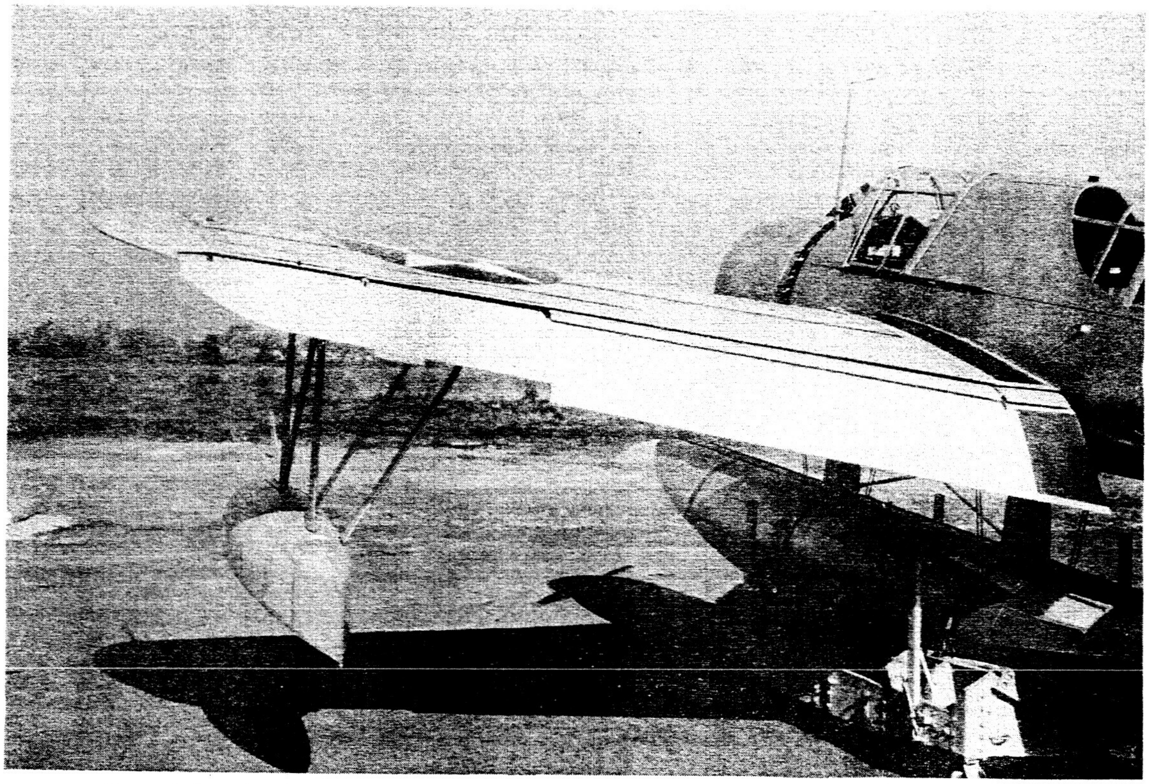

Figure 21.-Wing with flaps and ailerons down and spoilers neutral on the experimental airplane.

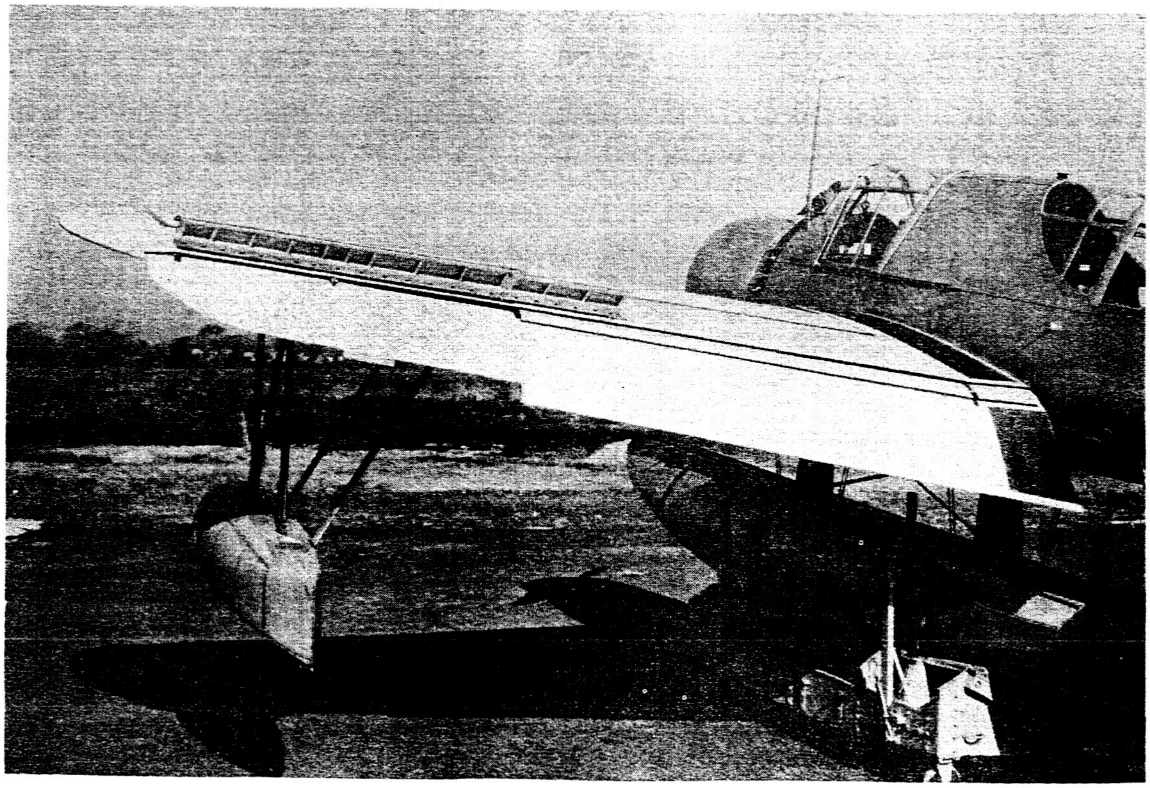

Figure 22.-Wing with flaps and ailerons down and spoilers deflected on the experimental airplane.

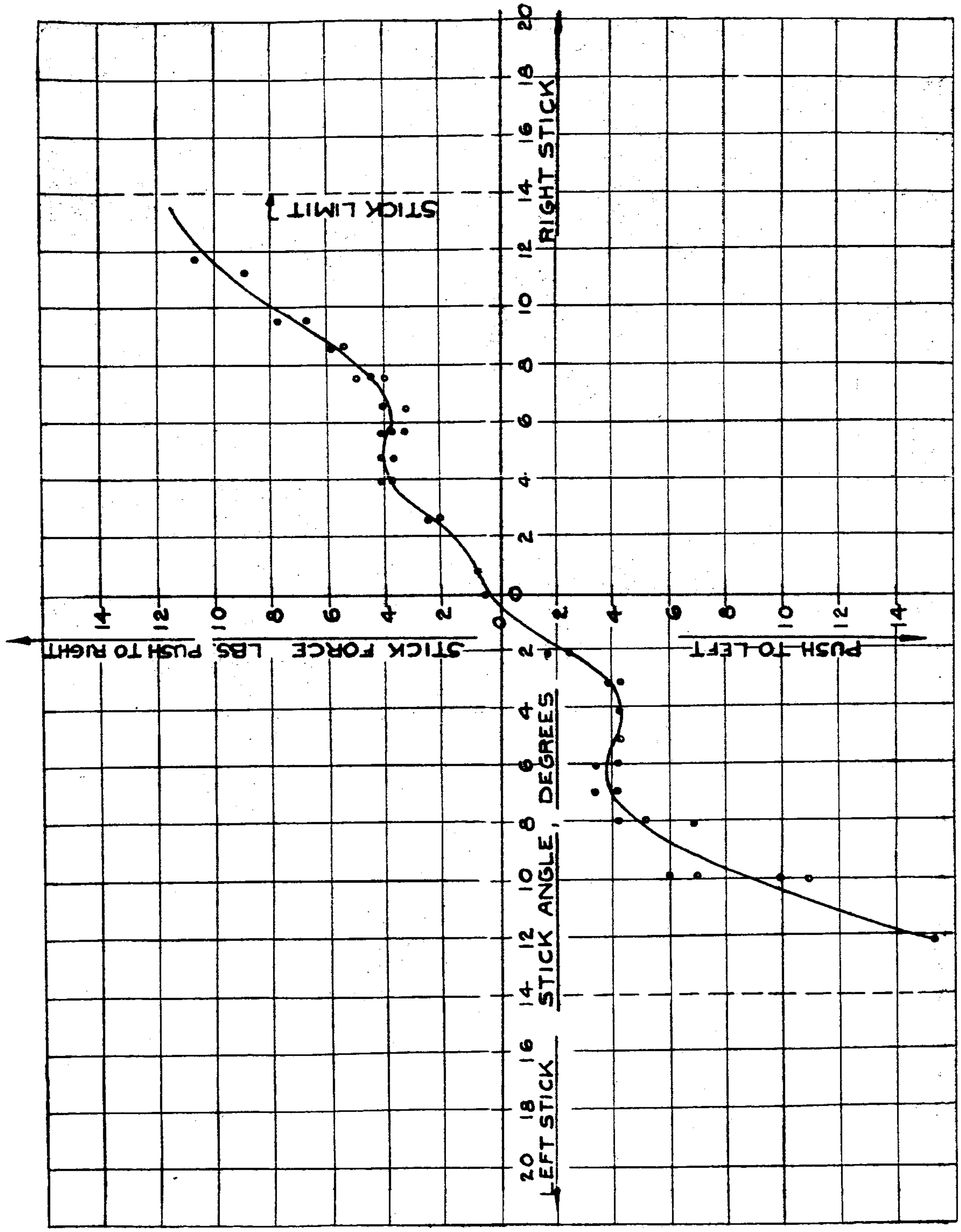

Figure 24.- Variation of stick force with stick angle for the experimental airplane without ventilated spoilers. Flaps and ailerons full down, 10 knots above stall.

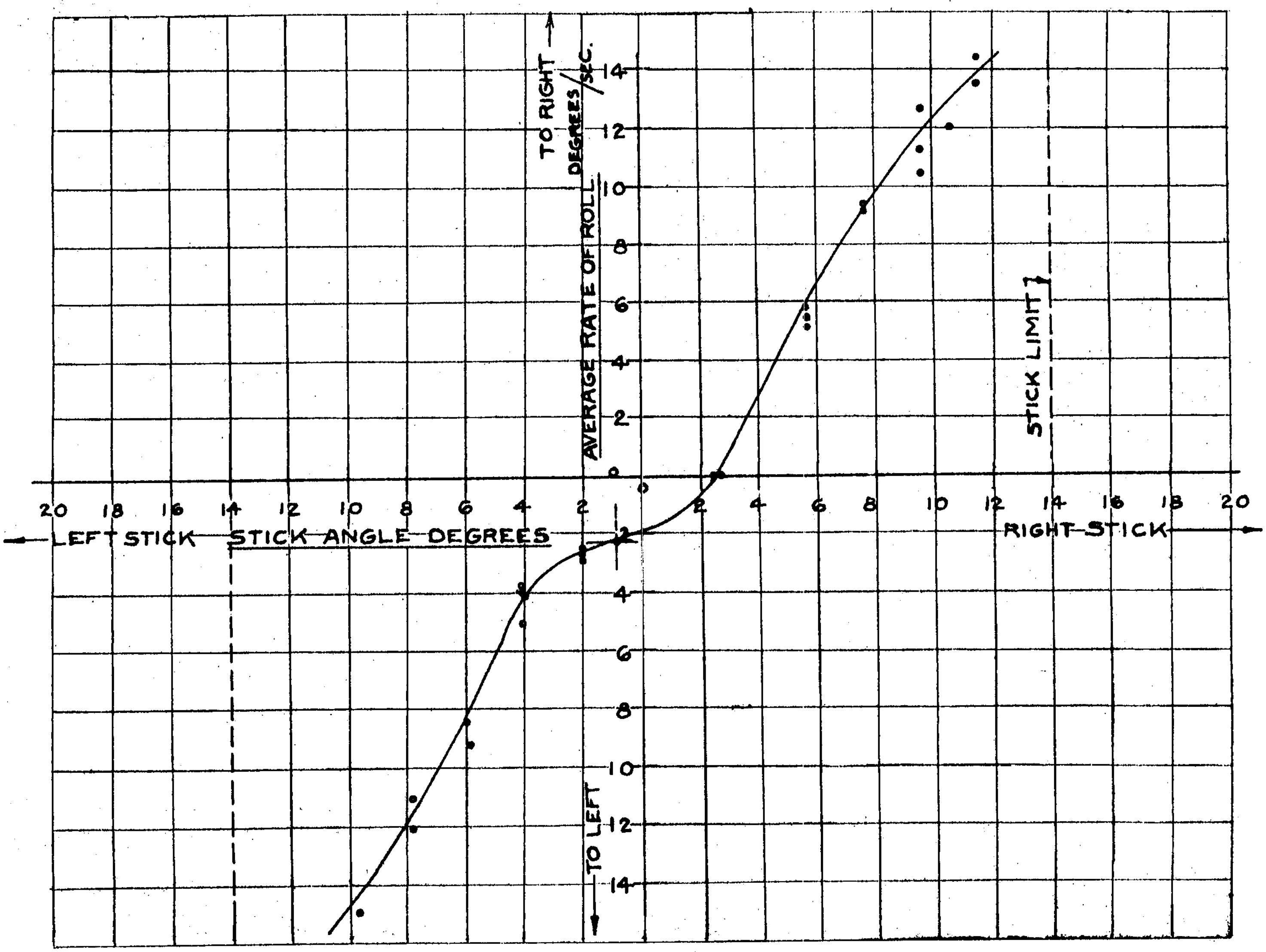

Figure 25.- Variation of average rate of roll with stick angle for the experimental airplane without ventilated spoilers. Flaps and ailerons full down, 10 knots above stall.

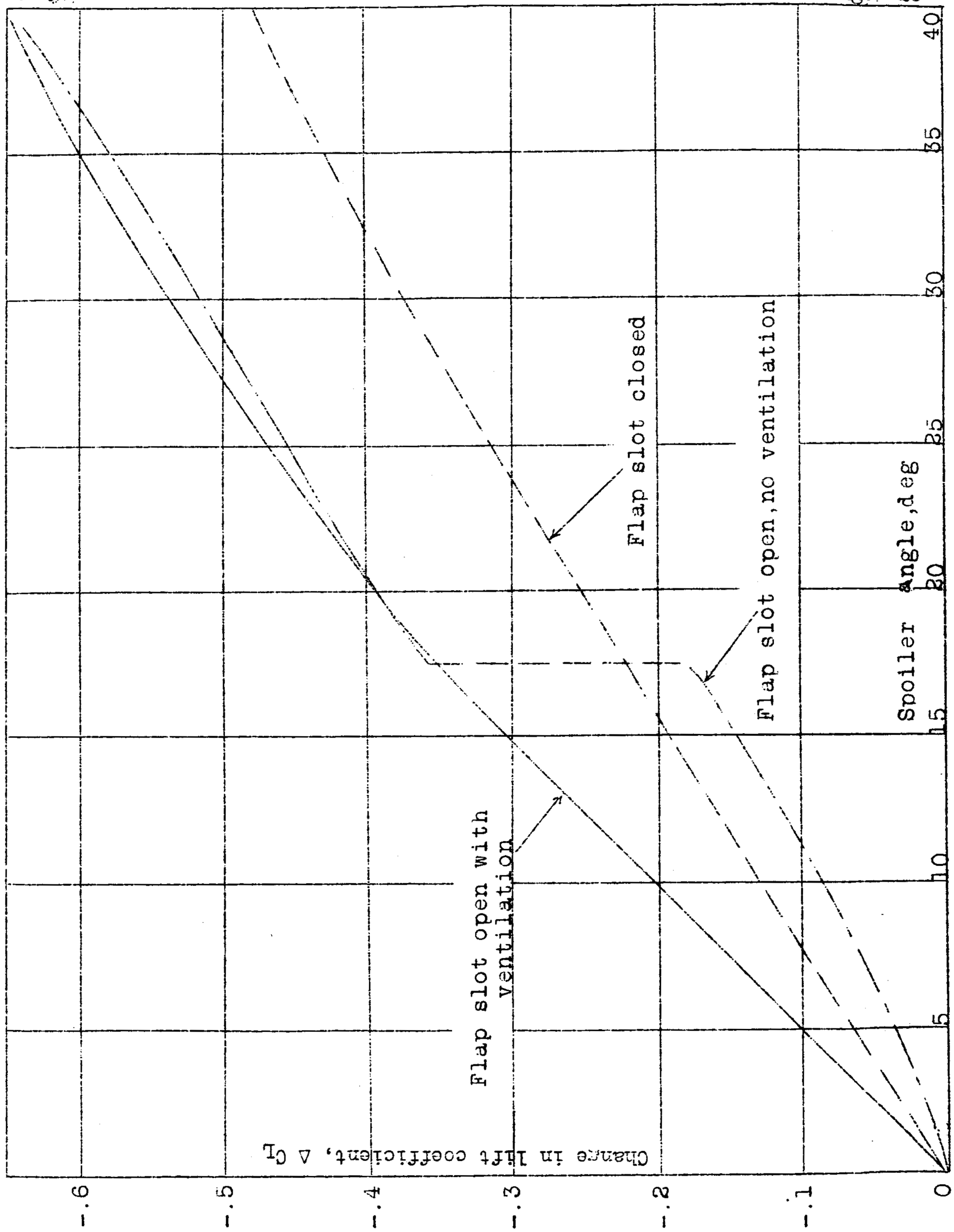

Figure 26.-Change in lift with spoiler deflection for various arrangements.

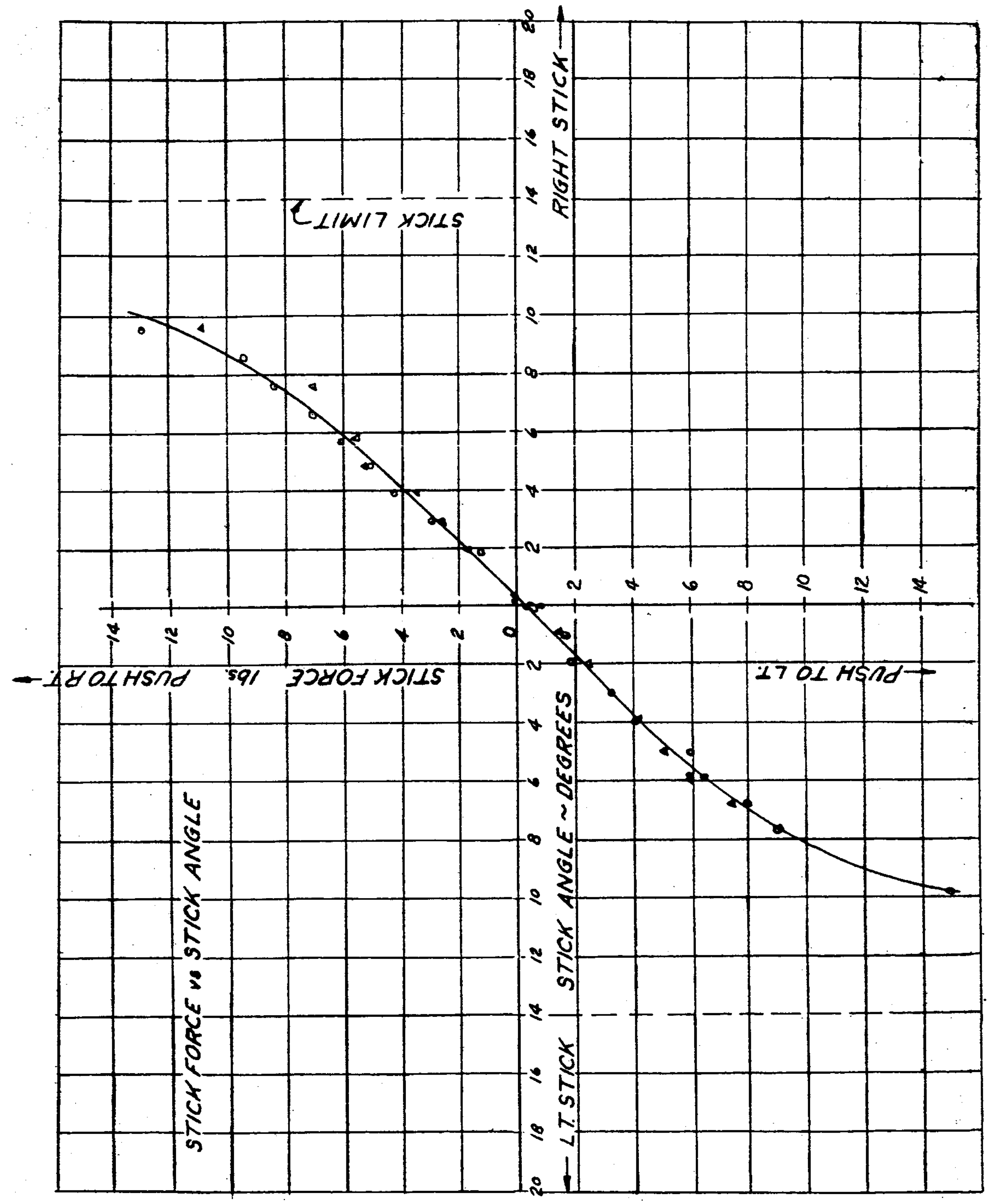

Figure 28.- Variation of stick force with stick angle for the experimental airplane with ventilated spoilers.

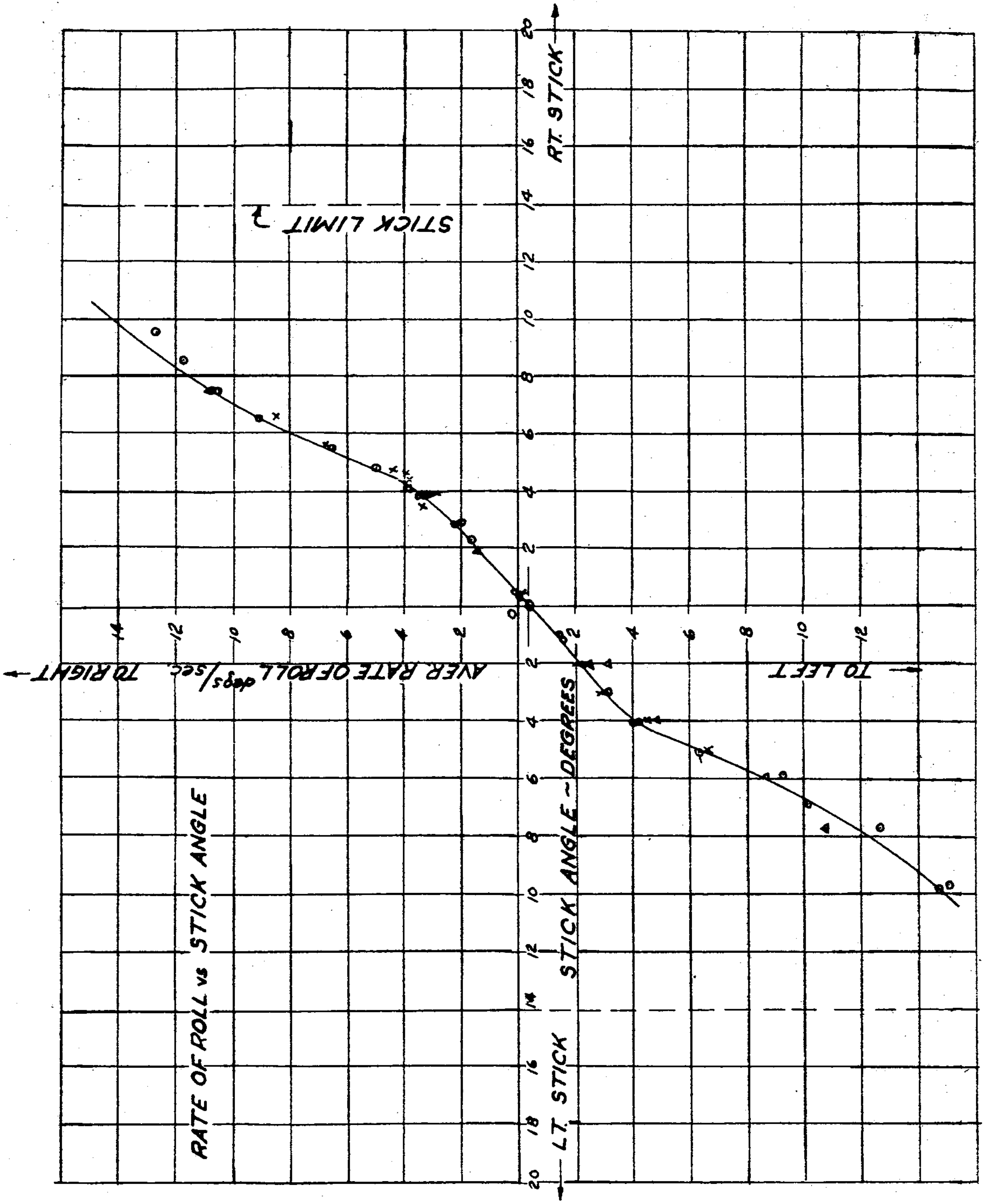

Figure 29.- Variation of average rate of roll with stick angle for the experimental airplane with ventilated spoilers.

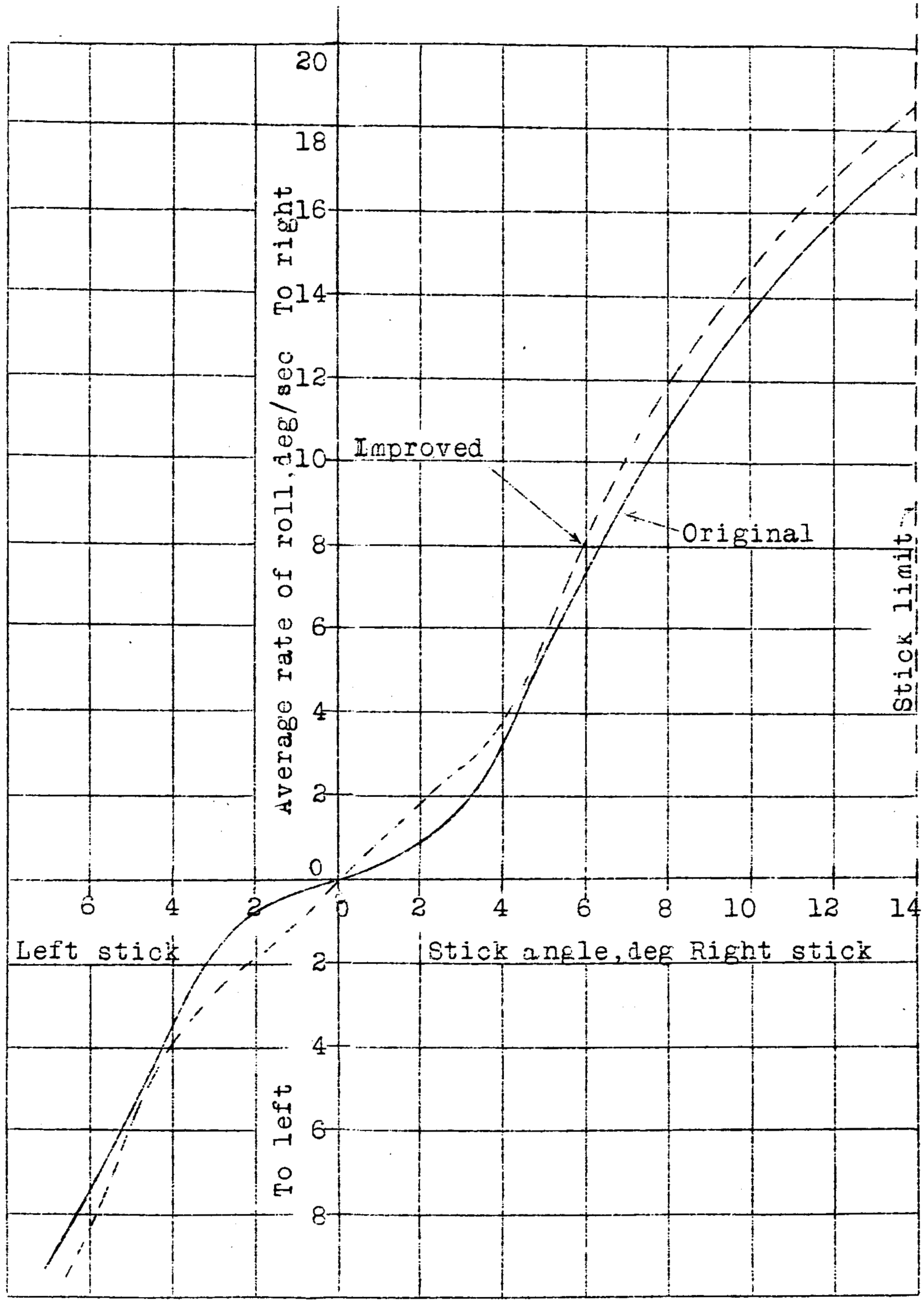

Figure 30.- Comparison of average rates of roll with stick angle for the experimental airplane with and without ventilated spoilers.